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IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

NOKIA CORPORATION and NOKIA, INC. Plaintiffs, v. INTERDIGITAL COMMUNICATIONS CORPORATION and INTERDIGITAL TECHNOLOGY CORPORATION Defendants.	Civil Action No. 05-16 ORIGINAL **DEMAND FOR JURY TRIAL**

COMPLAINT FOR DECLARATORY JUDGMENTS OF PATENT INVALIDITY AND NONINFRINGEMENT AND VIOLATIONS OF THE LANHAM ACT RELATING TO 3G MOBILE PHONE TECHNOLOGY

Plaintiffs Nokia Corporation and Nokia, Inc. (collectively referred to as "Nokia") file this Complaint for Declaratory Judgments Of Patent Invalidity And Noninfringement And Violations Of The Lanham Act Relating To 3G Mobile Phone Technology against Defendants InterDigital Communications Corporation and InterDigital Technology Corporation (collectively "InterDigital") and in support of their Complaint allege:

Nature And Basis Of Action

1. This is an action arising under the Declaratory Judgment Act, 28 U.S.C. §§ 2201 and 2202, the United States Patent Laws, 35 U.S.C. § 1 *et seq*. and the Lanham Act, 15 U.S.C. §1051 *et seq*.. Nokia requests declarations that: (i) the claims of various patents owned by InterDigital are invalid; and (ii) Nokia does not infringe any claim of the patents. Nokia seeks damages and injunctive relief for InterDigital's violations of the Lanham Act.

The Parties

2. Nokia Corporation is a global leader in the design, manufacture and supply of mobile handset and infrastructure products. Nokia Corporation is incorporated under the laws of Finland and has its principal place of business at Keilalahdentie 4, Espoo, Finland. Nokia, Inc. is incorporated under the laws of the state of Delaware and has a principal place of business at 6000 Connection Dr., Irving, Texas.

3. InterDigital Communications Corporation is incorporated under the laws of the State of Pennsylvania and has its principal place of business at 781 Third Avenue, King of Prussia, Pennsylvania. InterDigital Technology Corporation is incorporated under the laws of the State of Delaware and has its principal place of business at 300 Delaware Avenue, Suite 527, Wilmington, Delaware. Upon information and belief, InterDigital Technology Corporation is a wholly-owned subsidiary of InterDigital Communications Corporation.

Jurisdiction And Venue

4. This Court has jurisdiction over the subject matter of this action pursuant to 28 U.S.C. §§ 1331 and 1338, and the Declaratory Judgment Act, 28 U.S.C. §§ 2201 and 2202 based on federal question jurisdiction.

5. This Court has personal jurisdiction over InterDigital Communications Corporation and InterDigital Technology Corporation pursuant to the laws of the State of Delaware, including the Delaware long-arm statute, 10 Del. Code § 3104.

6. Venue is proper in this Court pursuant to 28 U.S.C. § 1391.

Facts Giving Rise To This Action

7. InterDigital has continued to represent for more than a decade both publicly and to the wireless handset industry that it has hundreds of patents that cover the principal wireless handset standards in the United States.

InterDigital's 2G Allegations

8. InterDigital began making allegations in the early 1990's that it had hundreds of patents that cover the principle "2G" mobile phone systems that implement the IS-54/136 and GSM mobile phone standards. The IS-54/136 and GSM standards are implemented through so-called 2G mobile phone systems using Time Division Multiple Access ("TDMA") technology. The IS-54/136 standard, or US-TDMA, is a standard developed in the United States and includes an early version of the standard, IS-54, and a later revision, IS-136. The GSM standard is a similar standard originally developed in Europe. Both IS-54/136 and GSM standards use TDMA as a means by which multiple mobile callers can use the same radio frequency concurrently.

9. InterDigital has in the past asserted certain of its 2G patents in court against Motorola, Inc. and Ericsson. The courts in the *Motorola* and *Ericsson* cases determined that most, if not all, of the asserted patents in those cases were either invalid or not infringed by mobile handset and infrastructure products used in the United States.

10. Most of the 2G patents asserted against Motorola and Ericsson by InterDigital were found to be invalid or not infringed for at least the following reasons:

- Many of the broad claims of the patents are limited to an obsolete speech compression method different from the method used in 2G systems in the United States;
- Many of the claims of the InterDigital 2G Patents are limited to a system with a single base station controlling a single cell. This single base station

limitation was used by InterDigital in the United States Patent Office in an effort to distinguish InterDigital's patents from prior art. No industry standard applicable to mobile handsets or their associated infrastructure contemplates such a system; instead, all current mobile systems in use in the United States use multiple base stations to control multiple cells.

- In an effort to distinguish prior art, many of the claims of the 2G patents were limited – during prosecution of the respective applications in the United States Patent Office and in subsequent litigation – to systems in which the call path is hard-wired, rather than controlled by software. Likewise, no industry standard applicable to mobile handsets or their associated infrastructure requires hard-wired call paths; instead, mobile systems in use in the United States during any relevant period are controlled dynamically by software.

Comparison of the claim limitations of InterDigital 2G patents and their prosecution histories to either the 2G industry standards or any systems in use in the United States shows that none of the hundreds of claims can be infringed by any of those 2G systems, including those utilized by companies such as Motorola, Ericsson and Nokia.

InterDigital's 3G Allegations

11. More recently, InterDigital has made allegations that it has patents that cover "3G" mobile systems that are currently being rolled out and further developed in the United States, referred to as the WCDMA and CDMA 2000 products. The WCDMA and CDMA 2000 standards are implemented through 3G mobile systems using Code Division Multiple Access ("CDMA") technology. The patents that InterDigital contends cover 3G mobile systems (hereafter collectively defined as "InterDigital's 3G Patents"), copies of which are attached as Exhibits A-R, include:

U.S. Patent No. 5,574,747, issued November 12, 1996 (the "'747 patent");

U.S. Patent No. 6,181,949, issued January 30, 2001 (the "'949 patent");

U.S. Patent No. 5,841,768, issued November 24, 1998 (the "'768 patent);

U.S. Patent No. 6,215,778, issued April 10, 2001 (the "'778 patent");

U.S. Patent No. 5,179,572, issued January 12, 1993 (the "'572 patent);

U.S. Patent No. 6,075,792, issued June 13, 2000 (the "'792 patent");

U.S. Patent No. 5,799,010, issued August 25, 1998 (the "'010 patent");

U.S. Patent No. 5,614,914, issued March 25, 1997 (the "'914 patent");

U.S. Patent No. 5,663,990, issued September 2, 1997 (the "'990 patent");

U.S. Patent No. 5,859,879, issued January 12, 1999 (the "'879 patent");

U.S. Patent No. 5,363,403, issued November 8, 1994 (the "'403 patent");

U.S. Patent No. 5,553,062, issued September 3, 1996 (the "'062 patent");

U.S. Patent No. 5,719,852, issued February 17, 1998 (the "'852 patent");

U.S. Patent No. 6,014,373, issued January 11, 2000 (the "'373 patent");

U.S. Patent No. 6,259,688, issued July 10, 2001 (the "'688 patent");

U.S. Patent No. 6,289,004, issued September 11, 2001 (the "'004 patent");

U.S. Patent No. 5,081,643, issued January 14, 1992 (the "'643 patent");

and

U.S. Patent No. 5,673,286, issued September 30, 1997 (the "'286 patent").

Although InterDigital contends that 3G mobile products made in the United States infringe its 3G Patents, all of InterDigital's 3G Patents are either invalid or not infringed by mobile handset and infrastructure products being rolled out on the United States. In particular, no Nokia product either sold in the United States or in development for sale in the United States infringes any valid claim of InterDigital's 3G Patents.

The License Agreement Between Nokia and InterDigital

12. Nokia and InterDigital are parties to three expressly interrelated agreements ("the Agreements"), the primary subject matter of which is a license to Nokia of the patents owned by InterDigital that InterDigital alleges are required to make and sell products that are compliant with the 2G and 3G telephone standards.

13. There is a dispute between Nokia and InterDigital as to the validity and scope of the patents that form the basis of the Agreements between them.

14. With respect to 2G products, despite the invalidity and/or narrowness of InterDigital's 2G patents as determined by the courts in the *Motorola* and *Ericsson* cases, InterDigital has publicly announced its intention to seek hundreds of millions of dollars in royalties from Nokia under the Agreements. Nokia has refused to pay the fees InterDigital is demanding. The parties are currently engaged in an International Chamber of Commerce Arbitration with respect to 2G products, entitled *Nokia Corporation v. InterDigital Communications Corporation and InterDigital Technology Corporation*, ICC Case Number 12 829/JNK.

15. With respect to 3G products, InterDigital continues to contend that its patents broadly cover 3G technology. Under the Agreements, Nokia is licensed to InterDigital's 3G patents only through the end of 2006. Nokia is currently designing, rolling out and further developing 3G products in the United States that will be manufactured and sold by Nokia after 2006.

16. Nokia has a reasonable apprehension that InterDigital will sue Nokia for patent infringement with respect to InterDigital's 3G patents.

17. InterDigital has a history of litigiousness. InterDigital's tactics are so well known, in fact, that *Forbes Magazine* published an article on InterDigital's litigation tactics, a copy of which is attached as Exhibit S. The article describes InterDigital as a company that uses litigation to "extract[] money from companies" that make handheld mobile phones. The article goes on to explain that InterDigital

> has earned enmity for its hardball enforcement of intellectual property rights. Virtually all of its $33 million profit from the first nine months [of 2003] has come from dragging customers like Ericsson and NEC Corp. through legal disputes over patents.

18. In an August 13, 2003, investor conference call, InterDigital's Chief Executive Officer, Howard Goldberg, acknowledged that InterDigital uses litigation as leverage in disputes with companies such as Nokia, included bringing injunctions to prevent the shipping of handsets. A copy of the transcript of the conference call is attached as Exhibit T (see page 14).

19. Such articles and statements by InterDigital executives support Nokia's reasonable apprehension that it has regarding InterDigital's willingness and intent to pursue patent infringement litigation against it.

20. Nokia has filed this suit because of InterDigital's efforts to enhance the value of its patents and Nokia's current need to design and develop 3G products that it will put into wide scale production after 2006.

21. Nokia seeks declarations that the claims of InterDigital's 3G Patents are either invalid or that Nokia's 3G products do not infringe any valid claim of those patents.

22. Although Nokia and InterDigital are currently arbitrating their 2G dispute, that dispute does not involve 3G products. Further, when Nokia attempted to raise the validity and scope of relevant InterDigital Patents in the arbitration by requesting that the

Arbitral Tribunal issue declarations on the validity and scope of InterDigital's 2G patents, InterDigital denied that declarations the invalidity and scope of its patents were arbitrable disputes under the Agreements.

COUNT I.
Declaration Of NonInfringement Of U.S. Patent No. 5,574,747

23. Nokia incorporates and re-alleges the averments contained in paragraphs 1 through 22, as if set forth in full.

24. The '747 patent relates to a system and method for adaptive power control of a spread spectrum transmitter of a mobile unit operating in a cellular-communications network having a plurality of mobile units in communication with a base station. Claims 1-3, 6-10 and 13-24 of the '747 patent are directed to a circuit in the mobile unit which changes the transmitted power of the handset so that the power level detected by the base station is at a "threshold level." This change is made using a step-size algorithm located in the mobile unit. The '747 patent requires that an accumulator in a handset store a series of prior power level values and uses this series in the power control algorithm used by the handset.

25. The WCDMA and CDMA 2000 3G standards require a command to raise or lower transmitted power within a WCDMA or CDMA 2000 mobile handset based on a power control algorithm. The standards specify that this adjustment be made by infrastructure, not by an algorithm contained in the handset. Accordingly, Nokia does not infringe claims 1-3, 6-10 and 13-24 of the '747 patent either literally or under the doctrine of equivalents, nor does it contribute to the infringement by others or actively induce others to infringe these claims of the '747 patent.

26. Accordingly, Nokia is entitled to a declaratory judgment of non-infringement of the '747 patent.

COUNT II.
Declaration Of Invalidity Of U.S. Patent No. 5,574,747

27. Nokia incorporates and re-alleges the averments contained in paragraphs 1 through 26, as if set forth in full.

28. Upon information and belief, at least claims 4-5 and 11-12 of the '747 patent are invalid. The '747 patent relates to a system and method for adaptive power control of a spread spectrum transmitter of a mobile unit operating in a cellular-communications network having a plurality of mobile units in communication with a base station. Claims 4-5 and 11-12 of the '747 patent are invalid in view of a 1993 IEEE publication, Viterbi & Viterbi, *Performance of Power-Controlled Wideband Terrestrial Digital Communication,* IEEE Transactions on Communications, vol. 41, no. 4, April 1993, pp. 559-569, because the limitations of these claims of the '747 patent are either contained in the Viterbi reference or are inherent in wireless systems, including IS-95 systems.

29. Accordingly, Nokia is entitled to a declaratory judgment of invalidity of claims 4-5 and 11-12 of the '747 patent.

COUNT III.
Declaration Of Noninfringement Of U.S. Patent No. 6,181,949

30. Nokia incorporates and re-alleges the averments contained in paragraphs 1 through 29, as if set forth in full.

31. The '949 patent relates to a method of controlling initial power ramp-up in CDMA systems by using short codes. Specifically, the patent relates to a system and

method of controlling transmission power during the establishment of a channel in a CDMA communication system utilizing the transmission of a short code from a subscriber unit to a base station during initial power ramp-up. According to the '949 patent, the short code is a sequence for detection by the base station which has a much shorter period than a conventional spreading code. The ramp-up starts from a power level that is guaranteed to be lower than the required power level for detection by the base station. The subscriber unit quickly increases transmission power while repeatedly transmitting the short code until the signal is detected by the base station. Once the base station detects the short code, it sends an indication to the subscriber unit to cease increasing transmission power. Various claims of the '949 patent require a second ramp-up rate after the initial power ramp-up.

32. Nokia does not infringe Claims 3-5, and 8-10 of the '949 patent. Each of those claims requires a second ramp-up period after the first ramp-up period. WCDMA and CDMA 2000 standards compliant handsets, including those of Nokia, do not have a second ramp-up period. Rather they have a single step increase in the power level after the initial ramp-up. Therefore, Nokia does not infringe Claims 3-5 or 8-10 of the '949 patent either literally or under the doctrine of equivalents, nor does it contribute to the infringement by others or actively induce others to infringe these claims of the '949 patent.

33. Accordingly, Nokia is entitled to a declaratory judgment of non-infringement of the '949 patent.

COUNT IV.
Declaration Of Invalidity Of U.S. Patent No. 6,181,949

34. Nokia incorporates and re-alleges the averments contained in paragraphs 1 through 33, as if set forth in full.

35. Upon information and belief, claims 1-2 and 6-7 of the '949 patent are invalid. As alleged in paragraph 31 above, the '949 patent relates to a method of controlling initial power ramp-up in CDMA systems.

36. Claims 1-2, and 6-7 of the '949 patent are either anticipated or obvious in view of the IS-95A standard. The IS-95A standard, published by the Telecommunications Industry Association, May 1995, discloses each limitation of these claims of the '949 patent.

37. Claims 1-2, and 6-7 of the '949 patent are also either anticipated or obvious in view of Viterbi & Viterbi, *Erlang Capacity of a Power Controlled CDMA System*, IEEE Journal on Selected Areas in communications, vol. 11, no. 6, August 1993, pp. 892-900. With respect to the ramp-up limitation contained in the claims of the '949 patent, Viterbi states "[i]f this initial power level is not sufficient for detection, and hence acknowledgement is not received, the user increases his power in constant decibel steps every frame until his request is acknowledged." Id. at p. 898.

38. Accordingly, Nokia is entitled to a declaratory judgment that Claims 1-2 and 6-7 of the '949 patent are invalid.

COUNT V.
Declaration Of Noninfringement Of U.S. Patent No. 5,841,768

39. Nokia incorporates and re-alleges the averments contained in paragraphs 1 through 38, as if set forth in full.

40. The '768 patent relates to a method of controlling initial power ramp-up in a CDMA system. Specifically, the patent relates to a system and method of controlling transmission power during the establishment of a channel in a CDMA communication system utilizing the transmission of a code from a subscriber unit to a base station during initial power ramp-up. The code is a sequence for detection by the base station which has a shorter period than a conventional spreading code. The ramp-up starts from a power level that is guaranteed to be lower than the required power level for detection by the base station. The subscriber unit quickly increases transmission power while repeatedly transmitting the code until the signal is detected by the base station. Once the base station detects the code, it sends an indication to the subscriber unit to cease increasing transmission power. The claims of the '768 patent also require transmission of a second periodic signal at a second ramp-up rate with the second ramp-up rate being less than said first ramp-up rate.

41. Nokia's products do not implement a second ramp-up rate function as claimed in the '768 patent nor does the WCDMA or CDMA 2000 standards require such a second ramp-up rate function. Therefore, Nokia does not infringe any claim of the '768 patent either literally or under the doctrine of equivalents, nor does it contribute to the infringement by others or actively induce others to infringe any claim of the '768 patent.

42. Accordingly, Nokia is entitled to a declaratory judgment of non-infringement of the '768 patent.

COUNT VI.
Declaration Of Noninfringement of U.S. Patent No. 6,215,778

43. Nokia incorporates and re-alleges the averments contained in paragraphs 1 through 42, as if set forth in full.

44. The '778 patent relates to a bearer channel modification system for a code division multiple access (CDMA) communication system.

45. According to the '778 patent, the multiple access, spread-spectrum communication system disclosed in the patent processes a plurality of information signals received by a Radio Carrier Station (RCS) over telecommunication lines for simultaneous transmission over a radio frequency (RF) channel as a code-division-multiplexed (CDM) signal to a group of Subscriber Units (SUs). The RCS receives a call request signal that corresponds to a telecommunication line information signal, and a user identification signal that identifies a user to receive the call. The RCS includes a plurality of Code Division Multiple Access (CDMA) modems, one of which provides a global pilot code signal. The modems provide message code signals synchronized to the global pilot signal. Each modem combines an information signal with a message code signal to provide a CDM processed signal. The RCS includes a system channel controller coupled to receive a remote call. An RF transmitter is connected to all of the modems to combine the CDM processed signals with the global pilot code signal to generate a CDM signal. The RF transmitter also modulates a carrier signal with the CDM signal and transmits the modulated carrier signal through an RF communication channel to the SUs. Each SU includes a CDMA modem which is also synchronized to the global pilot signal. The CDMA modem despreads the CDM signal and provides a despread information signal to the user. The system includes a closed loop power control system for maintaining a minimum system transmit power level for the RCS and the SUs, and system capacity management for maintaining a maximum number of active SUs for improved system performance.

46. Accordingly, the claims of the '778 patent are directed to having a subscriber unit change from one spread spectrum channel to another spread spectrum channel having a different data rate.

47. WCDMA standards compliant infrastructure manages the bandwidth assigned to a base station by changing the bandwidth of an assigned channel, rather than dynamically adding or removing channels. Nokia's WCDMA products do not infringe the '778 patent either literally or under the doctrine of equivalents, nor does Nokia contribute to the infringement by others or actively induce others to infringe any claim of the '778 patent.

48. In CDMA 2000 standards compliant systems, infrastructure manages the bandwidth assigned to a base station by determining the order, type, and number of channels assigned to handsets. Claims 4 of the '778 patent requires assigning multiple channels to a subscriber station at a time. CDMA 2000 infrastructure can manage the bandwidth of a handset solely by changing the type of channel currently assigned to the handset. Nokia's CDMA 2000 handsets do not infringe Claim 4 of the '778 patent either literally or under the doctrine of equivalents, nor does Nokia contribute to the infringement by others or actively induce others to infringe any claim of the '778 patent.

49. Nokia is entitled to a declaratory judgment of non-infringement of the '778 patent.

COUNT VII.
Declaration Of Invalidity of U.S. Patent No. 6,215,778

50. Nokia incorporates and re-alleges the averments contained in paragraphs 1 through 49, as if set forth in full.

51. As alleged in paragraph 44 above, the '778 patent relates to a bearer channel modification system for a code division multiple access (CDMA) communication system.

52. Upon information and belief, the claims of the '778 patent are invalid.

53. The claims of the '778 patent are directed to having a subscriber unit change from one spread spectrum channel to another spread spectrum channel having a different data rate.

54. The claims of the '778 patent are either anticipated or obvious in view of the IS-95a standard of May 1995, as modified by *Telecommunications Systems Bulletin, Support for 14.4 kbps Data Rate and PCS Interaction for Wideband Spread Spectrum Cellular Systems*, dated May 11, 1995. Each limitation of the claims of the '778 patent is disclosed or obvious in view of the IS-95a Telecommunications Systems Bulletin and/or the IS-95a standard.

55. The claims of the '778 patent are either anticipated or obvious in view of the A. Baier et al, *Design Study for a CDMA-Based Third-Generation Mobile Radio System*, IEEE Journal on Selected Areas in Communications, vol. 12, no. 4, May 1994. Each limitation of the claims of the '778 patent is disclosed in the Baier reference and/or the IS-95 standard.

56. Nokia is entitled to a declaratory judgment that the claims of the '778 patent are invalid.

COUNT VIII.
Declaration Of Noninfringement of U.S. Patent No. 5,179,572

57. Nokia incorporates and re-alleges the averments contained in paragraphs 1 through 56, as if set forth in full.

58. The '572 patent relates to a spread spectrum conference calling system and method. Specifically, the patent relates to a spread-spectrum-conference-calling receiver for use over multiple communications channels. The patent specifies that at each of a plurality of spread-spectrum transmitters, a transmitter-generic-chip-code generator generates a generic-chip-code signal and a transmitter-message-chip-code generator generates a message-chip-code signal. An EXCLUSIVE-OR gate spread-spectrum processes message data with the message-chip-code signal to generate a spread-spectrum signal. The combiner combines the generic-chip-code signal and the spread-spectrum-processed signal. A plurality of receiver-generic-chip-code generators generate a plurality of replicas of the generic-chip-code signal. Each receiver-generic mixer recovers a carrier signal from one of the plurality of received spread-spectrum-communications signals. A plurality of receiver-message-chip-code generators generate a plurality of replica of the message-chip-code signals. A plurality of receiver-message mixers despread one of the plurality of received spread-spectrum-communications signal as a modulated-data signal. Tracking and acquisition circuits use the recovered carrier signal for synchronizing the replicas of the generic-chip-code signals to the recovered carrier signals, respectively. An envelope detector demodulates the modulated-data signal as a demodulated signal.

59. The claims of the '572 patent, therefore, are directed to a system and method for synchronously demodulating a plurality of modulated data signals on a

plurality of spread spectrum channels in a conference call. The conference call is sent on multiple channels and the subscriber unit demodulates all of the calls in order to listen to them.

60. Nokia's CDMA 2000 and WCDMA products do not provide for conference calling such that the calls are combined from separate spread spectrum channels at the mobile handset. Therefore, Nokia's CDMA 2000 handsets do not infringe the '572 patent either literally or under the doctrine of equivalents, nor does Nokia contribute to the infringement by others or actively induce others to infringe any claim of the '572 patent.

61. Nokia is entitled to a declaratory judgment of noninfringement of the '572 patent.

COUNT IX.
Declaration Of Invalidity of U.S. Patent No. 5,179,572

62. Nokia incorporates and re-alleges the averments contained in paragraphs 1 through 61, as if set forth in full.

63. As alleged in paragraph 58 above, the '572 patent relates to a spread spectrum conference calling system and method. Specifically, the claims of the '572 patent are directed to a system and method for synchronously demodulating a plurality of modulated data signals on a plurality of spread spectrum channels in a conference call. The conference call is sent on multiple channels and the subscriber unit demodulates all of the calls in order to listen to them.

64. Upon information and belief, if the claims of the '572 patent are not limited to conference calling, the '572 patent is invalid as anticipated or obvious.

COUNT X.
Declaration Of Noninfringement of U.S. Patent No. 6,075,792

65. Nokia incorporates and re-alleges the averments contained in paragraphs 1 through 64, as if set forth in full.

66. The '792 patent relates to a CDMA communication system which selectively allocates bandwidth upon demand. The '792 patent discusses a CDMA wireless digital communication system which supports all types of voice and data communications while utilizing a minimum amount of bandwidth for the particular application. According to the '792 patent, the system efficiently allocates ISDN bandwidth on demand by a subscriber. Upon initialization of the subscriber unit, the system establishes a channel and generates the necessary spreading codes to support the highest capacity channel desired by the subscriber unit. Portions of the communication spectrum bandwidth are not reserved until actually required by the subscriber unit. The '792 patent states that since the call setup is performed at the beginning of a call from that subscriber unit, including the assignment of spreading codes, a subscriber unit can quickly gain access to the portion of the spectrum that is required to support the particular application.

67. The '792 patent, therefore, is directed to bandwidth allocation of the spread spectrum by utilizing different channels that may be added or removed, and selectively used to increase bandwidth. The claims of the '792 patent are directed to subscriber units and base stations that have the capability to use, establish and tear down such channels.

68. The WCDMA standard does not dynamically add or tear down channels to establish different data rates. Nokia's products comply with the WCDMA standard and therefore do not implement the bandwidth allocation process claimed in the '792 patent.

69. Nokia's products also do not establish or use a wireless ISDN channel. Accordingly, Nokia's products do not infringe the '792 patent, including at least claims 1, 3-6, 10-12, and 17-18, because those claims require the use of an ISDN channel.

70. Nokia's handsets also do not assign or allocate wireless channels. Such decisions are done by infrastructure. Therefore, Nokia's products do not infringe the claims of the '792 patent, including at least claim 9, either literally or under the doctrine of equivalents, nor does Nokia contribute to the infringement by others or actively induce others to infringe any claim of the '792 patent.

71. Upon information and belief, Nokia's CDMA 2000 handsets do not directly infringe any claim of the '792 patent, because those claims require claim elements that are not present in Nokia's handsets. Nokia's CDMA 2000 handsets also do not contributorily infringe any claim of the '792 patent because only CDMA 2000 infrastructure, as opposed to handsets, could meet various claim limitations. Upon information and belief, for each such claim limitation not present in Nokia's CDMA 2000 handsets, there exist substantial uses and infrastructure implementations that do not infringe any claim of the '792 patent. Therefore, Nokia's products do not infringe any claim of the '792 patent either literally or under the doctrine of equivalents, nor does Nokia contribute to the infringement by others or actively induce others to infringe any claim of the '792 patent.

72. Nokia is entitled to a declaratory judgment of noninfringement of the '792 patent.

COUNT XI.
Declaration Of Invalidity of U.S. Patent No. 6,075,792

73. Nokia incorporates and re-alleges the averments contained in paragraphs 1 through 72, as if set forth in full.

74. As alleged in paragraph 66 above, the '792 patent relates to a CDMA communication system which selectively allocates bandwidth on demand.

75. Upon information and belief, at least claims 2, 7, 8, and 13-15 of the '792 patent are invalid in view of at least *IS-95 Enhancements for Multi-Media Services* by Chih-Lin I et al. Each of the elements of these claims of the '792 patent are disclosed or obvious in light of the *IS-95 Enhancements for Multi-Media Services* which was published at least as early as Autumn of 1996.

76. Upon information and belief, at least claims 2, 7, 8, and 13-15 of the '792 patent are invalid in view of at least U.S. Patent No. 6,072,787 ("the '787 patent") assigned to Nokia. Each of the elements of these claims of the '792 patent is disclosed or obvious in light of the '787 patent, which was filed on July 5, 1996.

77. Nokia is entitled to a declaratory judgment of invalidity with respect to at least claims 2, 7, 8, and 13-15 of the '792 patent.

COUNT XII.
Declaration Of Noninfringement of U.S. Patent No. 5,799,010

78. Nokia incorporates and re-alleges the averments contained in paragraphs 1 through 77, as if set forth in full.

79. The '010 patent relates to a code division multiple access (CDMA) communication system. The '010 patent discusses a multiple access, spread-spectrum communication system that processes a plurality of information signals received by a Radio Carrier Station (RCS) over telecommunication lines for simultaneous transmission over a radio frequency (RF) channel as a code-division-multiplexed (CDM) signal to a group of Subscriber Units (SUs). The RCS receives a call request signal that corresponds to a telecommunication line information signal, and a user identification signal that identifies a user to receive the call. The RCS includes a plurality of Code Division Multiple Access (CDMA) modems, one of which provides a global pilot code signal. The modems provide message code signals synchronized to the global pilot signal. Each modem combines an information signal with a message code signal to provide a CDM processed signal. The RCS includes a system channel controller coupled to receive a remote call. An RF transmitter is connected to all of the modems to combine the CDM processed signals with the global pilot code signal to generate a CDM signal. The RF transmitter also modulates a carrier signal with the CDM signal and transmits the modulated carrier signal through an RF communication channel to the SUs. Each SU includes a CDMA modem which is also synchronized to the global pilot signal. The CDMA modem despreads the CDM signal and provides a despread information signal to the user.

80. The claims of the '010 patent are therefore directed to a CDMA system that uses a "global pilot code signal" for synchronizing modems. The global pilot code is defined as "a channel with a spreading code but no data modulation."

81. The WCDMA standard does not require that message signals be synchronized to a global pilot code signal as claimed in the '010 patent. In Nokia's WCDMA systems, message channels are not synchronized to a global pilot code signal and therefore do not infringe the '010 patent.

82. Nokia's CDMA 2000 handsets do not directly infringe claims 1-4 and 9 of the '010 patent because those claims require "means for receiving a call request signal" and "modem processing means." These claim limitations, as properly construed, are not present in Nokia's CDMA 2000 handsets. Nokia's CDMA 2000 handsets likewise do not contributorily infringe claim 1-4 and 9 of the '010 patent because only CDMA 2000 infrastructure, as opposed to handsets, could contain "means for receiving a call request signal." There likewise exist substantial uses and infrastructure implementations that do not meet the "means for receiving a call request signal," as properly construed, required in claims 1-4 and 9 of the '010 patent. Therefore, Nokia's CDMA 2000 products do not infringe claims 1-4 and 9 of the '010 patent either literally or under the doctrine of equivalents, nor does Nokia contribute to the infringement by others or actively induce others to infringe claims 1-4 and 9 of the '010 patent.

83. Nokia's CDMA 2000 handsets likewise do not infringe claims 5-8 of the '010 patent. Nokia's CDMA 2000 handsets do not calculate the acquisition signal as required by those claims. Therefore, Nokia's CDMA 2000 products do not infringe claims 5-8 of the '010 patent either literally or under the doctrine of equivalents, nor contribute to the infringement by others or actively induces others to infringe claims 5-8 of the '010 patent.

84. Nokia's CDMA 2000 handsets also do not infringe any claim of the '010 patent because Nokia's CDMA 2000 handsets are not synchronized to a pilot code as required by the claims of the '010 patent. Therefore, Nokia's CDMA 2000 products do not infringe any claim of the '010 patent either literally or under the doctrine of equivalents, nor does Nokia contribute to the infringement by others or actively induce others to infringe any claim of the '010 patent.

85. Nokia is entitled to a declaratory judgment of noninfringement of the '010 patent.

COUNT XIII.
Declaration Of Invalidity of U.S. Patent No. 5,799,010

86. Nokia incorporates and re-alleges the averments contained in paragraphs 1 through 85, as if set forth in full.

87. Upon information and belief, the claims of the '010 patent are invalid. As alleged in paragraph 79 above, the '010 patent relates to a code division multiple access (CDMA) communication system that uses a "global pilot code signal" for synchronizing modems.

88. Each of the claims of the '010 is anticipated by or obvious in light of the IS-95a standard or the TR45 draft to the IS-95a standard entitled *Mobile Station – Base Station Compatibility Standard for dual-Mode Wideband Spread Spectrum Cellular System*, PN-3144, dated December 9, 1992, both of which were published before the filing date of the '010 patent.

89. Each of the claims of the '010 patent is anticipated or obvious in light of Gaudenzi, et al., *Chip Timing Synchronization in an All-Digital Band-Limited DS/SS Modem*, IEEE Conference on Communications (ICC), 1991, pp. 1688-1692.

90. The claims of the '010 patent are therefore either anticipated or rendered obvious by the IS-95a standard, the TR45 draft to the IS-95a standard, and/or Gaudenzi, et al.

91. Nokia is entitled to a declaratory judgment of invalidity of the claims of the '010 patent.

COUNT XIV.
Declaration Of Noninfringement of U.S. Patent No. 5,614,914

92. Nokia incorporates and re-alleges the averments contained in paragraphs 1 through 91, as if set forth in full.

93. The '914 patent relates to a wireless telephone distribution system with time and space diversity transmission for determining receiver location. The '914 patent discloses a wireless communication system that combines time and space diversity to reduce fading. In particular, the '914 patent discloses a data packet which carries digital telephone traffic that is transmitted at three different times from three different antennas. The mobile subscriber receiver receives the same data packet at three different times from the three different antennas, and uses the best data packet or combination of the data packets to reduce the effects of fading. A transfer station receives a time division multiplex multiple access (TDMA) signal from a base station carrying telephone data packet traffic to form three data packet repeats at spatially diverse antennas locations. The transfer station further modulates a code division multiple access (CDMA) system using a TDMA signal which links the mobile subscriber receiver to the transfer station. Each data packet received at the transfer station is retransmitted at three different times to the mobile subscriber station on a CDMA link. The time division and code division multiplex signals transmitted from space diversity antennas provide the ability to

determine subscriber location using the same communication signals which are used for the primary telephone data communication. Specifically, the subscriber station receiver uses the absolute and relative time of arrival of the three repeated data packets to determine the respective distances of the mobile subscriber station to the three transmitting antennas. Because the transmitting antennas are at known fixed locations, receiver location is determined.

94. The '914 patent, therefore, claims a system and method relating to determining the location of a mobile subscriber station using an observed time difference of arrival (OTDOA) of wireless signals from at least three transmitting stations.

95. Nokia does not implement OTDOA in its WCDMA or CDMA 2000 wireless products and therefore does not infringe the '914 patent.

96. Nokia is entitled to a declaratory judgment of noninfringement of the '914 patent.

COUNT XV.
Declaration Of Noninfringement of U.S. Patent No. 5,663,990

97. Nokia incorporates and re-alleges the averments contained in paragraphs 1 through 96, as if set forth in full.

98. Nokia does not infringe any claim of the '990 patent. The '990 patent relates to a wireless telephone distribution system with time and space diversity transmission and has a similar disclosure as that of the '914 patent alleged in paragraph 93 above.

99. The claims of the '990 patent focus on a time switched transmission technique wherein the same data is broadcast twice in two different time slots to achieve time switched transmit diversity.

100. Two open loop transmit diversity schemes are included in the WCDMA standard. These two schemes include Time Switched Transmit Diversity (TSTD) and Space Time Transmit Diversity (STTD). TSTD involves periodically switching the transmit antenna for separate time divided slots and retransmitting the same information. STTD involves coding the signal for separate antennas and transmitting on those antennas simultaneously.

101. All but two of the independent claims (9 and 23) of the '990 patent include a limitation to a communication system or method where the transmitted signal is encoded using a pseudorandom number to achieve spread spectrum modulation. Claims 9 and 23, which do not contain the pseudorandom number encoding limitation, contain a limitation to a system or method where a transfer station is utilized between the base station and the user equipment.

102. None of Nokia's WCDMA or CDMA 2000 products infringe claim 9 or 23 of the '990 patent, or their dependent claims. No implementation of either standard includes a transfer station as required by those claims. Nokia's handsets when used with such systems, therefore, do not infringe claim 9 or 23 of the '990 patent, or the claims which depend from them.

103. Nokia's CDMA 2000 handsets do not infringe any claim of the '990 patent because no CDMA 2000 system has been implemented with either TSTD or STTD. Nokia's handsets when used with such systems, therefore, do not infringe any claim of the '990 patent.

104. The WCDMA standard specifies that the only channel that employs a TSTD scheme is the synchronization channel. In the WCDMA standard, the

synchronization channel is not spread as required by all of the independent claims of the '990 patent (except claims 9 and 23).

105. When the WCDMA standard employs STTD, the "same data packet" is not transmitted as required by the claims of the '990 patent. Additionally, when the WCDMA standard employs STTD, data packets are not discarded as required by the claims of the '990 patent.

106. Nokia's WCDMA systems comply with the WCDMA standard. Nokia's systems therefore do not infringe the claims of the '990 patent.

107. Nokia is entitled to a declaratory judgment of noninfringement of the '990 patent.

COUNT XVI.
Declaration Of Noninfringement of U.S. Patent No. 5,859,879

108. Nokia incorporates and re-alleges the averments contained in paragraphs 1 through 107, as if set forth in full.

109. The '879 patent relates to a wireless telephone distribution system with time and space diversity transmission and has a similar disclosure as that of the '914 and '990 patents alleged in paragraphs 93 and 100-101 above.

110. The claims of the '879 patent focus on a time divided transmission technique wherein the same data is broadcast twice in two different time slots to achieve time transmit diversity.

111. The claims of the '879 patent include a limitation to a communication system or method where the transmitted signal is encoded using a pseudorandom number to achieve spread spectrum modulation.

112. As explained in paragraph 104 above, the only channel in WCDMA that employs TSTD is the standard synchronization channel and that channel is not spread as required by all of the claims of the '879 patent.

113. As explained in paragraph 105 above, when the WCDMA standard employs STTD, the "same data packet" is not transmitted as required by the claims of the '879 patent..

114. When the WCDMA standard employs STTD it uses the same spreading code instead of different spreading codes as required by the claims of the '879 patent.

115. Nokia's WCDMA systems comply with the WCDMA standard. Nokia's systems therefore do not infringe the claims of the '879 patent.

116. Upon information and belief, Nokia's CDMA 2000 handsets do not infringe any claim of the '879 patent because no CDMA 2000 systems have been implemented with either TSTD or STTD. Nokia's handsets when used with such systems, therefore, do not infringe any claim of the '879 patent.

117. Nokia is entitled to a declaratory judgment of noninfringement of the '879 patent.

COUNT XVII.
Declaration Of Noninfringement of U.S. Patent Nos. 5,363,403; 5,553,062; 5,719,852; 6,014,373; and 6,259,688

118. Nokia incorporates and re-alleges the averments contained in paragraphs 1 through 117, as if set forth in full.

119. Nokia does not infringe any claim of the '403 patent, the '062 patent, the '852 patent, the '373 patent, or the '688 patent.

120. The '403 patent relates to a spread spectrum CDMA subtractive interference canceler and method. The patent discloses a spread-spectrum code division multiple access interference canceler for reducing interference in a direct sequence CDMA receiver having N chip-code channels. The interference canceler includes a plurality of correlators or matched filters, a plurality of spread-spectrum-processing circuits, subtracting circuits, and channel correlators or channel-matched filters. Using a plurality of chip-code signals, the plurality of correlators despreads the spread-spectrum CDMA signal as a plurality of despread signals, respectively. The plurality of spread-spectrum-processing circuits use a timed version of the plurality of chip-code signals, for spread-spectrum processing the plurality of despread signals, respectively, with a chip-code-signal corresponding to a respective despread signal. For recovering a code channel using an i.sup.th chip-code-signal, the subtracting circuits subtract from the spread-spectrum CDMA signal, each of the N-1 spread-spectrum-processed-despread signals thereby generating a subtracted signal. The N-1 spread-spectrum-processed-despread signals do not include the spread-spectrum-processed-despread signal of the i.sup.th channel of the spread-spectrum CDMA signal. The channel correlator or channel-matched filter despreads the subtracted signal.

121. The '062 patent is a continuation-in-part of the '403 patent. The '852 patent, the '373 patent and the '688 patent are all continuations of the '403 patent.

122. The '403 patent, the '062 patent, the '852 patent, the '373 patent and the '688 patent (the "Subtractive Interference Cancellation patents") all disclose and claim a method and system for subtractive interference cancellation in a multi-channel, spread spectrum CDMA system.

123. In a multiple channel spread spectrum system, interference is created by the multiple channels. When one channel is decoded or despread, interference from the other channels will appear as noise. The system and method in the Subtractive Interference Cancellation patents claim a series of components to remove this noise by subtracting the signals corresponding to other channels from the input signal prior to processing the channel of interest.

124. Nokia's WCDMA digital wireless systems do not implement subtractive interference cancellation techniques and therefore do not infringe any claim of the Subtractive Interference Cancellation patents.

125. Nokia's CDMA 2000 handsets do not implement subtractive interference cancellation techniques as required by InterDigital's patents and therefore do not infringe any claim of the Subtractive Interference Cancellation patents.

126. Nokia is entitled to a declaratory judgment of noninfringement of the Subtractive Interference Cancellation patents.

COUNT XVIII.
Declaration Of Noninfringement of U.S. Patent No. 6,289,004

127. Nokia incorporates and re-alleges the averments contained in paragraphs 1 through 126, as if set forth in full.

128. The '004 patent relates to adaptive cancellation of fixed interferers and discloses a base station which cancels the effects of known fixed interference sources by producing a signal substantially free from the interference sources to thereby increase channel capacity. The adaptive interference canceler system includes a main antenna for receiving signals from other communication stations and at least one directional antenna

directed toward an interference source. The main and directional antennas are coupled to the adaptive canceler, which weights signals received by the directional antennas and sums the weighted signals to produce a cancellation signal. The adaptive canceler subtracts the cancellation signal from the signals received by the main antenna to provide an output signal substantially free from the interference generated by the one or more known interference sources.

129. The claims of the '004 patent all require that the system include a directional antenna with four coplanar feeds mounted near the main base station antenna.

130. Neither the WCDMA standard, nor the CDMA 2000 standard, require the use of directional antennas.

131. Nokia's WCDMA and CDMA 2000 products comply with the WCDMA and CDMA 2000 standards, and do not employ directional antennas. Nokia's systems therefore do not infringe any claim of the '004 patent.

132. Nokia is entitled to a declaratory judgment of noninfringement of the '004 patent.

COUNT XIX.
Declaration Of Noninfringement of
U.S. Patent No. 5,081,643

133. Nokia incorporates and re-alleges the averments contained in paragraphs 1 through 132, as if set forth in full.

134. The '643 patent relates to a spread spectrum multipath receiver apparatus and method. In particular, the '643 patent discloses an apparatus for adapting to receive a particular path, having the greatest amplitude, of a spread-spectrum signal with multipath. According to the patent, the spread-spectrum signal is modulated by a chip-code. A chip-

code generator generates a chip-code signal having the same chip-code as the spread-spectrum signal. A plurality of shift registers shift the chip-code signal by a plurality of time delays. First and second ring counters generate first and second sequencing signals for controlling first and second switching devices. The first switching device successively switches between a plurality of taps of the shift registers in a direction of increasing or decreasing delays for generating the chip-code signal with the first time delay. The second switching device successively switches between the plurality of taps of the shift registers in a direction of increasing or decreasing delays for generating the chip-code signal with a second time delay. A first correlator correlates the spread-spectrum signal received at the input with the chip-code signal with the first time delay. A second correlator correlates the spread-spectrum signal received at the input with the chip-code signal with the second time delay. A comparator generates first and second comparator signals by comparing the outputs of the first correlator and the second correlator.

135. Nokia's WCDMA and CDMA 2000 products do not include "delay means" or "shift registers" as claimed in the '643 patent. The WCDMA and CDMA 2000 standards likewise to not require such "delay means" or "shift registers." Instead of delaying a code after it is generated by the code generator, as required by the '643 patent, Nokia's WCDMA products modify the speed of the code generator by internal clocking. Instead of delaying a code after it is generated by the code generator with shift registers, as required by the '643 patent, Nokia's CDMA 2000 products choose from multiple samples of the input signal or reprogram the code generator. Nokia's products therefore do not infringe any claim of the '643 patent either literally or under the doctrine of

equivalents, nor does Nokia contribute to the infringement by others or actively induce others to infringe any claim of the '643 patent.

136. Nokia's WCDMA products also do not include delay codes by one or more chip intervals, as required by claims 1 and 2 of the '643 patent because Nokia's WCDMA products shift the speed of the internal code generator by 1/2 chip. Nokia's WCDMA products do not infringe claims 1 and 2 of the '643 patent either literally or under the doctrine of equivalents, nor contribute to the infringement by others or actively induce others to infringe claims 1 and 2 of the '643 patent.

137. Nokia's WCDMA products also do not include a difference amplifier as required by the claims of the in the '643 patent. Therefore, Nokia's WCDMA products do not infringe the claims of the '643 patent either literally or under the doctrine of equivalents, nor does Nokia contribute to the infringement by others or actively induce others to infringe the claims of the '643 patent.

COUNT XX.
Declaration Of Noninfringement of
U.S. Patent No. 5,673,286

138. Nokia incorporates and re-alleges the averments contained in paragraphs 1 through 137, as if set forth in full.

139. The '286 patent relates to a spread spectrum multipath processor system and method. In particular, the '286 patent discloses a spread-spectrum system and method for providing high capacity communications through multipath compensation. The multipath processor system includes a first plurality of correlators, a second plurality of correlators, a first adder, a second adder, and a selector device or a combiner device is provided for tracking a spread-spectrum signal arriving in a plurality of groups. The first

plurality of correlators despreads a first group of spread-spectrum signals as a first group of despread signals which are added by the first adder to generate a first combined-despread signal. The second plurality of correlators despreads a second group of spread-spectrum signals as a second group of despread signals which are added by the second adder to generate a second combined-despread signal. The selector device selects either the first or the second combined-despread signal and outputs the selected signal. According to the patent, the combiner device alternatively combines the first and the second combined-despread signals and outputs the combined signal.

140. Nokia's WCDMA and CDMA 2000 products do not include "combining" or "selecting" signals twice as required by the claims of the '286 patent. Nokia's products therefore do not infringe any claim of the '286 patent either literally or under the doctrine of equivalents, nor does Nokia contribute to the infringement by others or actively induce others to infringe any claim of the '286 patent.

COUNT XXI.
Violation Of § 43(a) Of The Lanham Act

141. Nokia incorporates and re-alleges the averments contained in paragraphs 1 through 140, as if set forth in full.

142. InterDigital has used false or misleading descriptions or representations in connection with its patent portfolio, the WCDMA Standard, the CDMA 2000 standard, Nokia's products, the applicability of InterDigital's patents to Nokia's products, and the applicability of InterDigital's patents to 3G wireless standards within the meaning of 15 U.S.C. §1125(a) (§43(a) of the Lanham Act). This misconduct of InterDigital has inhibited the development of 3G technology, damaged Nokia's business and its reputation in the wireless market.

143. Upon information and belief, InterDigital has repeatedly made public statements that its patent portfolio covers the practice of 3G wireless phone systems and the sale of 3G compliant products. These statements are false because InterDigital's patents are not necessary to practice 3G wireless phone standards.

144. These false statements are material and, upon information and belief, have caused actual deception or have a tendency to deceive a substantial portion of the intended audience.

145. InterDigital's misrepresentations about the scope and validity of its patents and how these patents apply to Nokia's products have injured Nokia in its business and have damaged Nokia's reputation.

146. Upon information and belief, InterDigital has made these false statements in bad faith and with knowledge of their falsity.

JURY DEMAND

Nokia demands a trial by jury.

PRAYER FOR RELIEF

WHEREFORE, Nokia respectfully requests that the Court enter judgment:

(a) That Nokia does not infringe the '747 patent, the '949 patent, the '768 patent, the '778 patent, the '572 patent, the '792 patent, the '010 patent, the '914 patent, the '990 patent, the '879 patent, the '403 patent, the '062 patent, the '852 patent, the '373 patent, the '688 patent, the '004 patent, the '643 patent, or the '286 patent;

(b) That the '747 patent, the '949 patent, the '778 patent, the '792 patent, the '572 patent and the '010 patent are invalid;

(c) That InterDigital's statements concerning the scope and validity of its 3G patents are false and misleading, in violation of § 43(a) of the Lanham Act;

(d) Awarding Nokia damages in an amount to be determined at trial for Nokia's loss;

(e) Granting Nokia its attorneys' fees and costs; and

(f) Granting such other and further relief as the Court deems just and proper.

MORRIS, NICHOLS, ARSHT & TUNNELL

Jack B. Blumenfeld

Jack B. Blumenfeld (#1014)
Julia Heaney (#3052)
1201 N. Market Street
Wilmington, DE 19801
(302) 658-9200
Attorneys for NOKIA CORPORATION and NOKIA, INC.

Of Counsel:

ALSTON & BIRD LLP

Peter Kontio
Patrick J. Flinn
Gardner S. Culpepper
Keith E. Broyles
1201 West Peachtree Street
Atlanta, GA 30309-3424
404-881-7000

January 12, 2005

Exhibit A

US005574747A

United States Patent [19]

Lomp

[11] Patent Number: 5,574,747

[45] Date of Patent: Nov. 12, 1996

[54] SPREAD SPECTRUM ADAPTIVE POWER CONTROL SYSTEM AND METHOD

[75] Inventor: Gary R. Lomp, Centerport, N.Y.

[73] Assignee: InterDigital Technology Corporation, Wilmington, Del.

[21] Appl. No.: 368,710

[22] Filed: Jan. 4, 1995

[51] Int. Cl.[6] H04K 1/00

[52] U.S. Cl. 375/200; 455/33.1; 349/59; 380/34

[58] Field of Search 375/200, 349; 380/34; 455/33.1, 59, 61, 103; 379/59, 63

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Primary Examiner—Stephen Chin
Assistant Examiner—T. Ghebretinsae
Attorney, Agent, or Firm—David Newman & Associates, P.C.

[57] ABSTRACT

A system and method for adaptive power control of a spread spectrum transmitter of a mobile unit operating in a cellular-communications network having a plurality of mobile units in communication with a base station. In response to a received signal from the mobile unit, the received signal having a first spread-spectrum signal and an interfering signal, an automatic gain control (AGC) circuit within the base station generates an AGC-output signal which is despread by base despreader and then processed as a received-power level. The received power level is then compared to a threshold level to generate a power command signal. The power command signal is transmitted to the mobile station as a second spread-spectrum signal. The mobile station despreader despreads the second spread-spectrum signal as a power adjust signal and, responsive to the power adjust signal, increases or decreases the power level of the first spread spectrum signal.

24 Claims, 23 Drawing Sheets

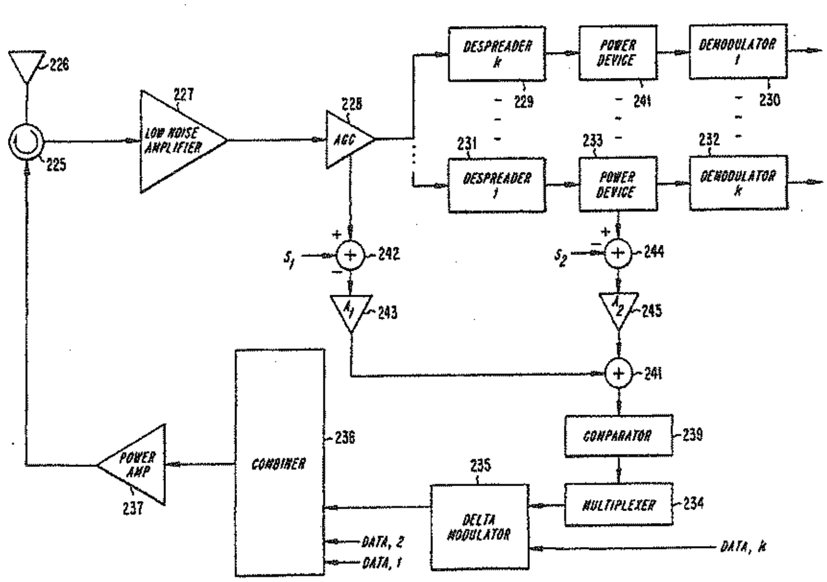


FIG. 1

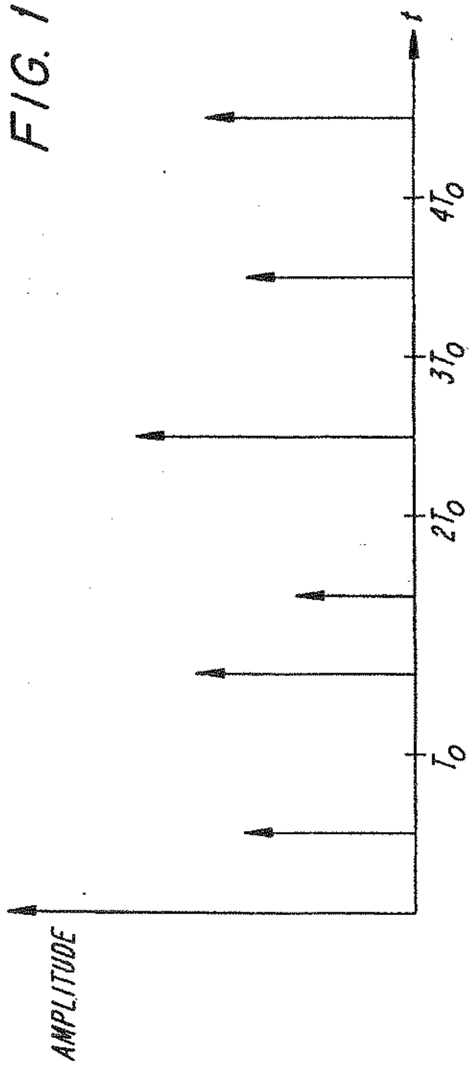
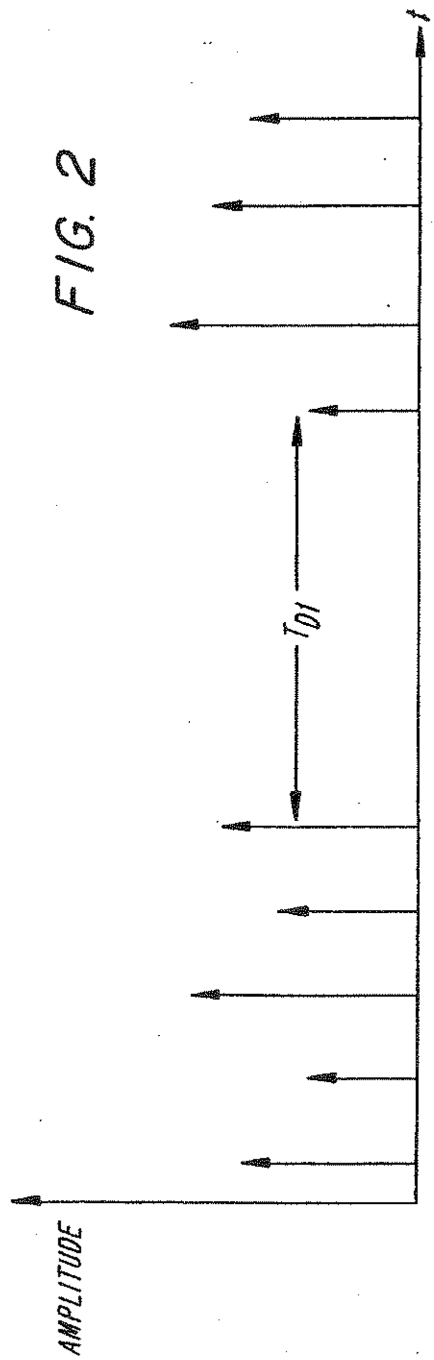
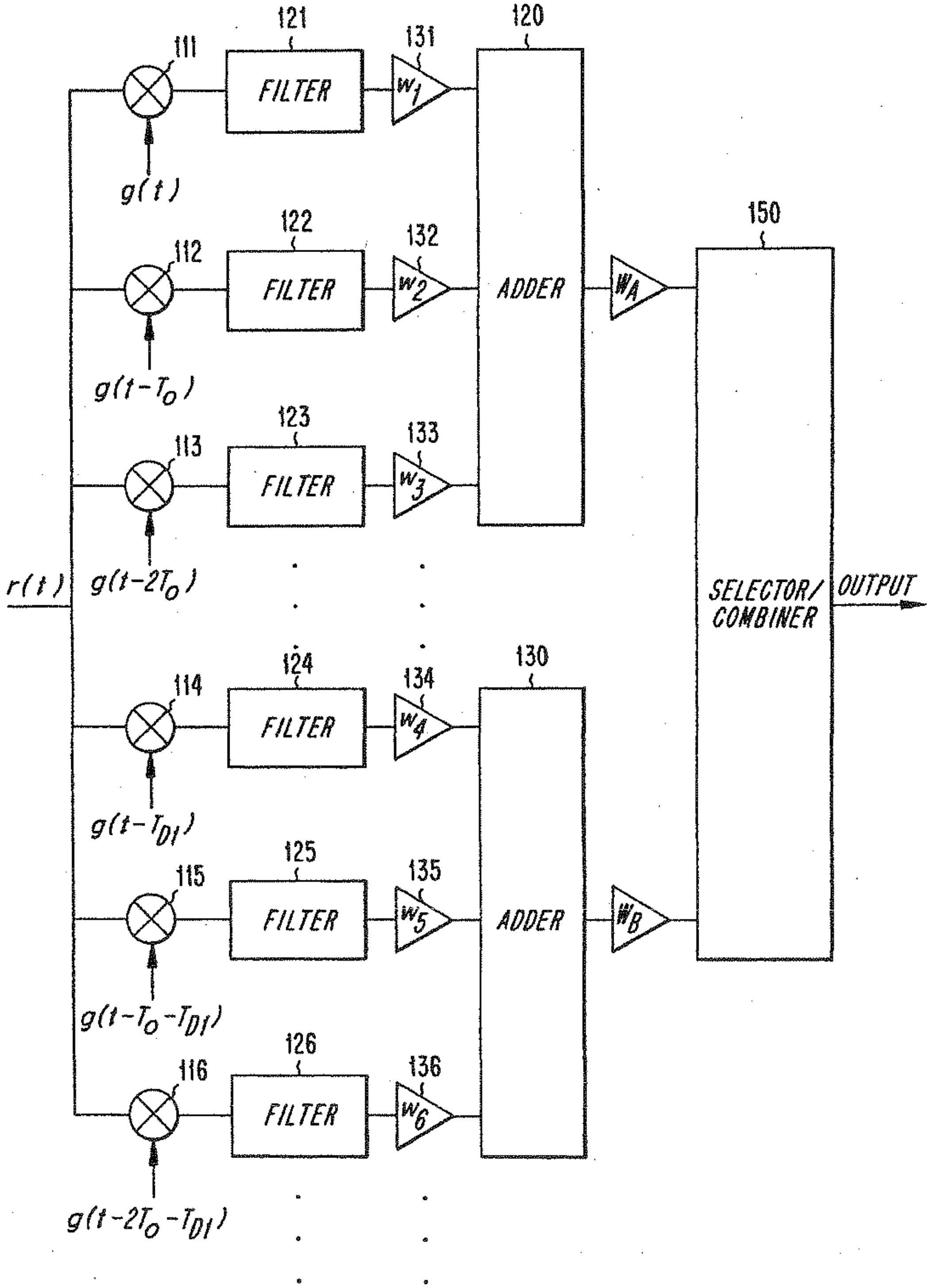


FIG. 2





121
111
131
120
FILTER
w_1
g(t)
122
132
150
112
FILTER
w_2
ADDER
W_A
$g(t-T_O)$
123
133
113
FILTER
w_3
r(t)
$g(t-2T_O)$
SELECTOR/
COMBINER
OUTPUT
124
134
130
114
FILTER
w_4
$g(t-T_{D1})$
125
135
115
FILTER
w_5
ADDER
W_B
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126
136
116
FILTER
w_6
$g(t-2T_O-T_{D1})$

FIG. 3

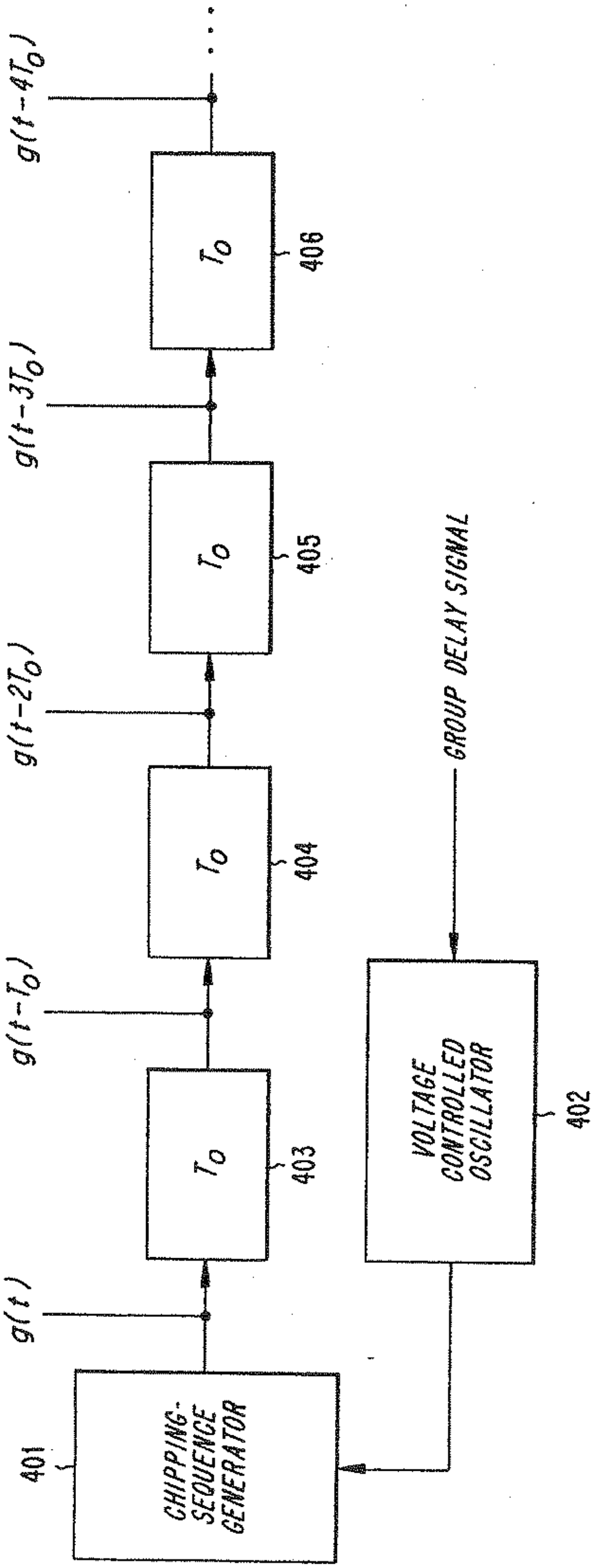

CHIPPING-SEQUENCE GENERATOR
401
VOLTAGE CONTROLLED OSCILLATOR
402
GROUP DELAY SIGNAL
T_O
403
404
405
406
$g(t)$
$g(t-T_O)$
$g(t-2T_O)$
$g(t-3T_O)$
$g(t-4T_O)$

FIG. 4

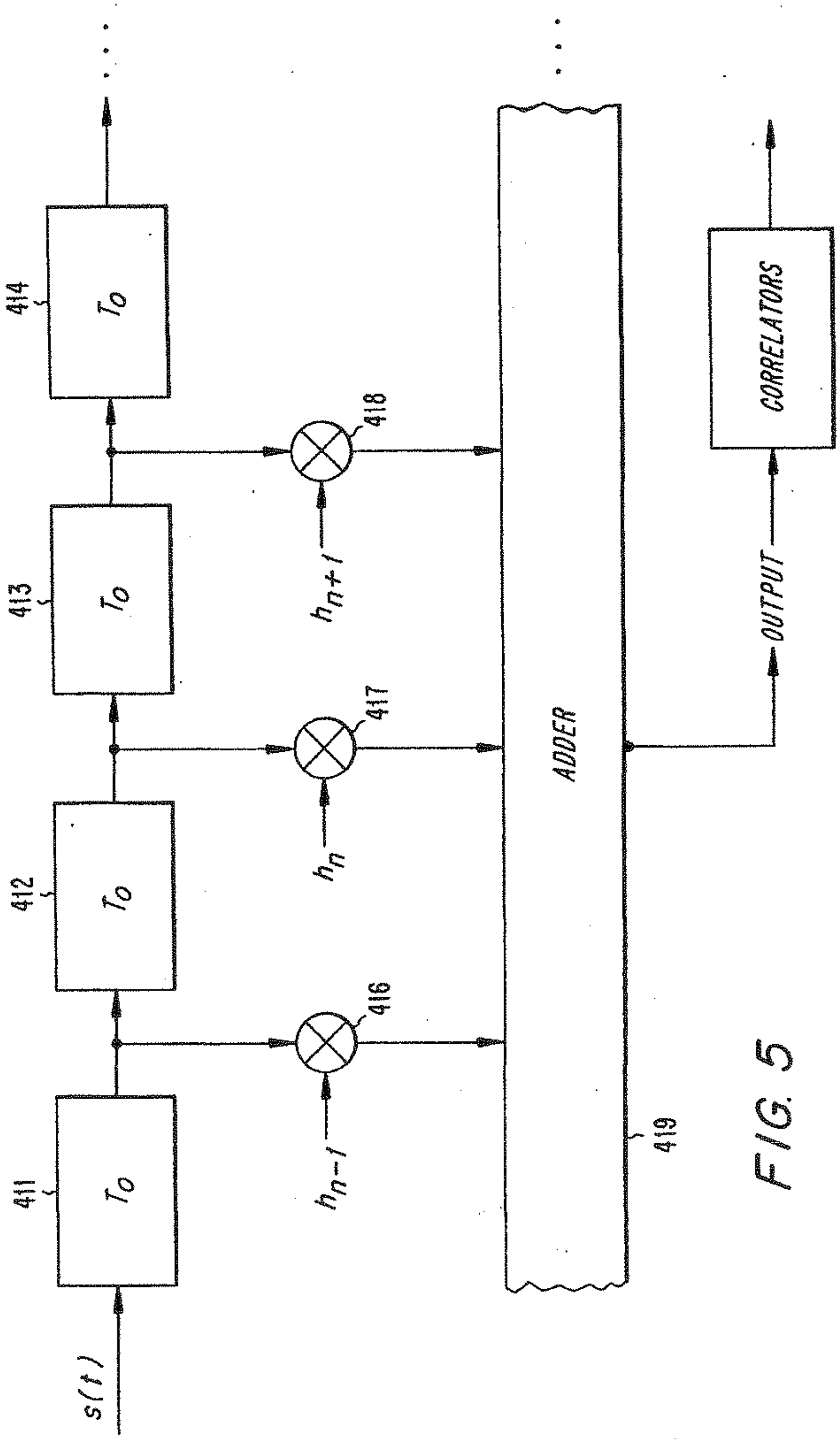

s(t)
411
412
413
414
To
To
To
To
416
417
418
h_{n-1}
h_n
h_{n+1}
ADDER
419
OUTPUT
CORRELATORS

FIG. 5

FIG. 6

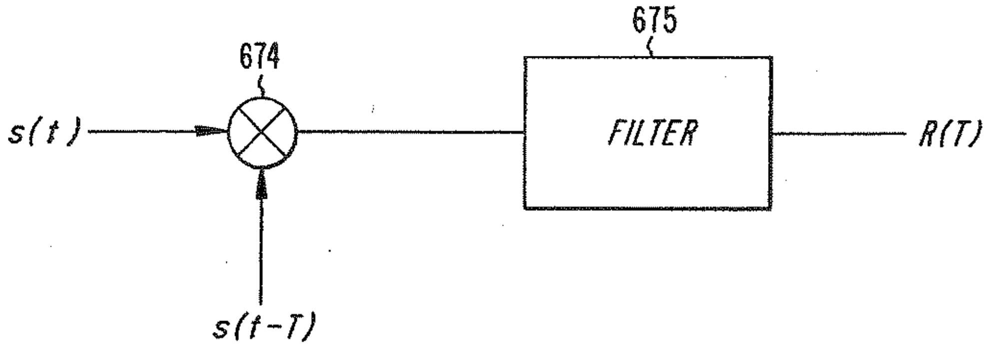


FIG. 7

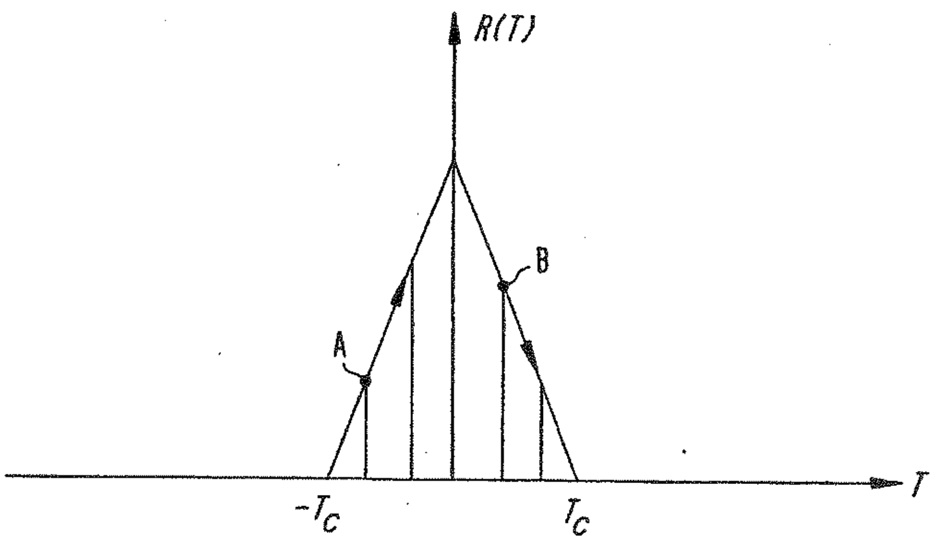
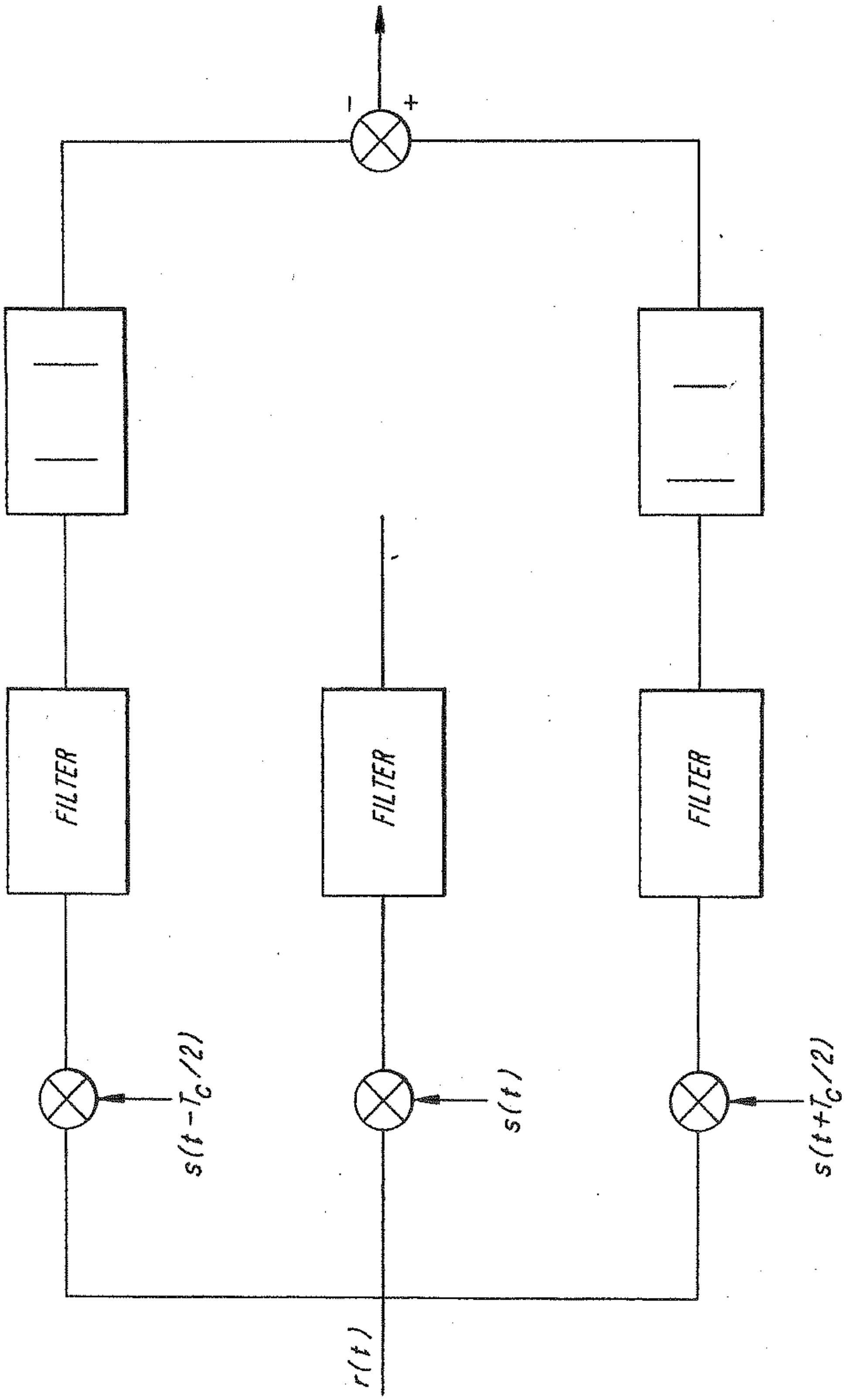
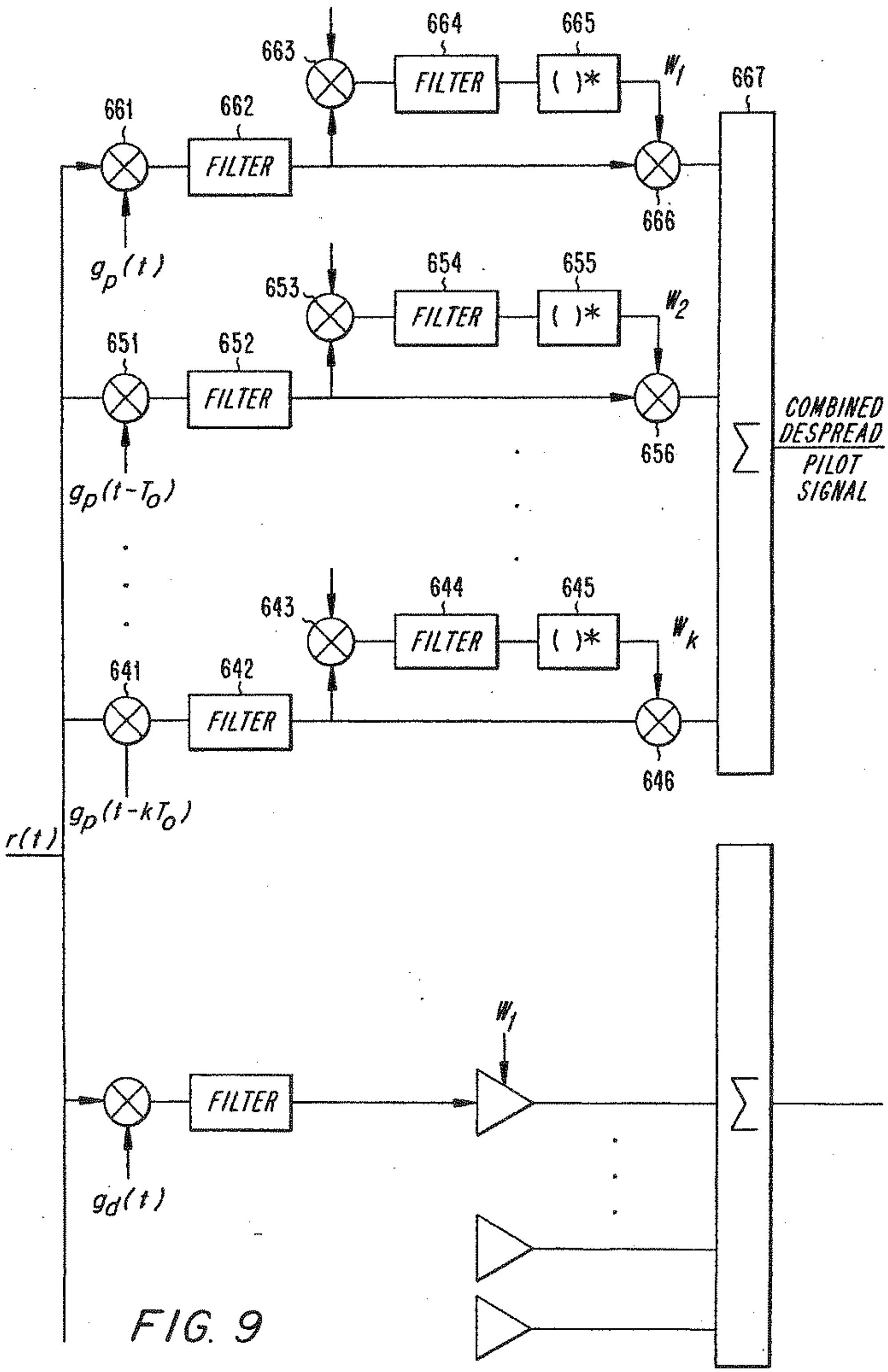


FIG. 8





663
664
FILTER
665
( )*
W_1
667
661
662
FILTER
666
$g_p(t)$
653
654
FILTER
655
( )*
W_2
651
652
FILTER
656
COMBINED DESPREAD PILOT SIGNAL
$g_p(t-T_0)$
643
644
FILTER
645
( )*
W_k
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FILTER
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FILTER
W_1
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FIG. 9

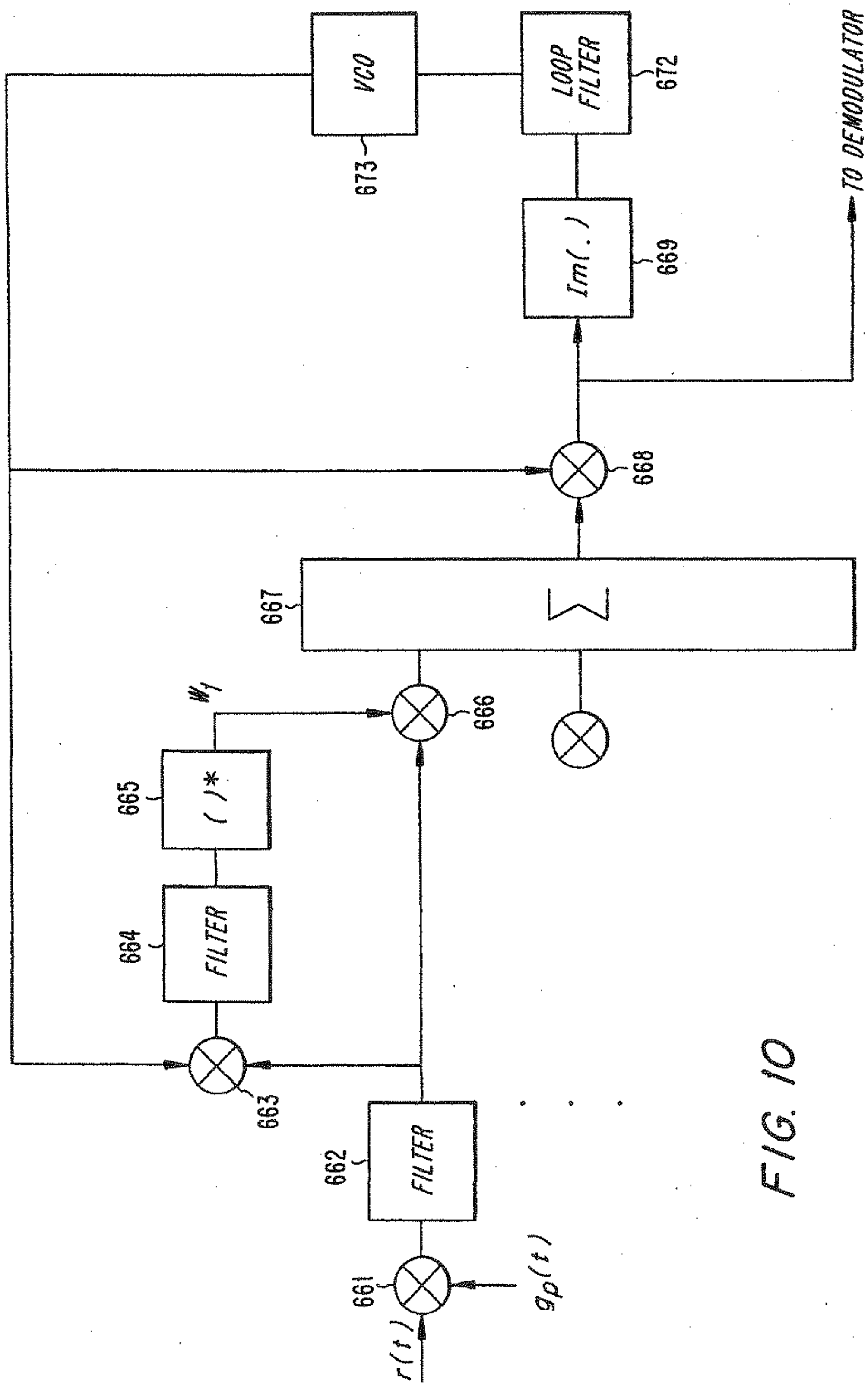

VCO
673
LOOP FILTER
672
TO DEMODULATOR
Im(.)
669
668
667
Σ
W_1
666
665
( )*
664
FILTER
663
662
FILTER
661
r(t)
$g_p(t)$

FIG. 10

FIG. 11

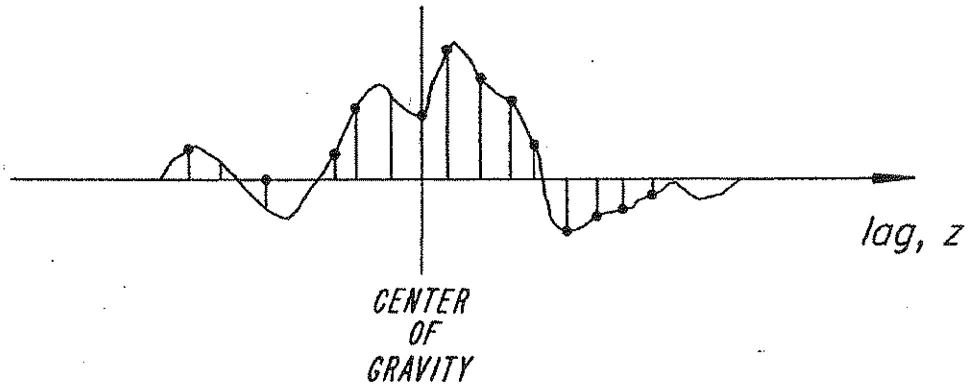


FIG. 12

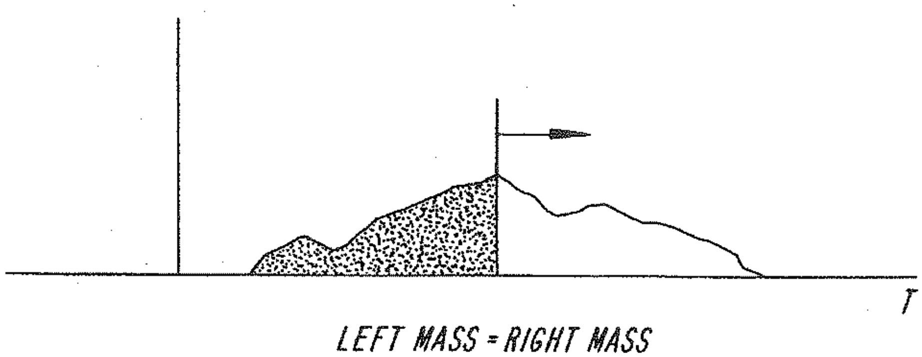
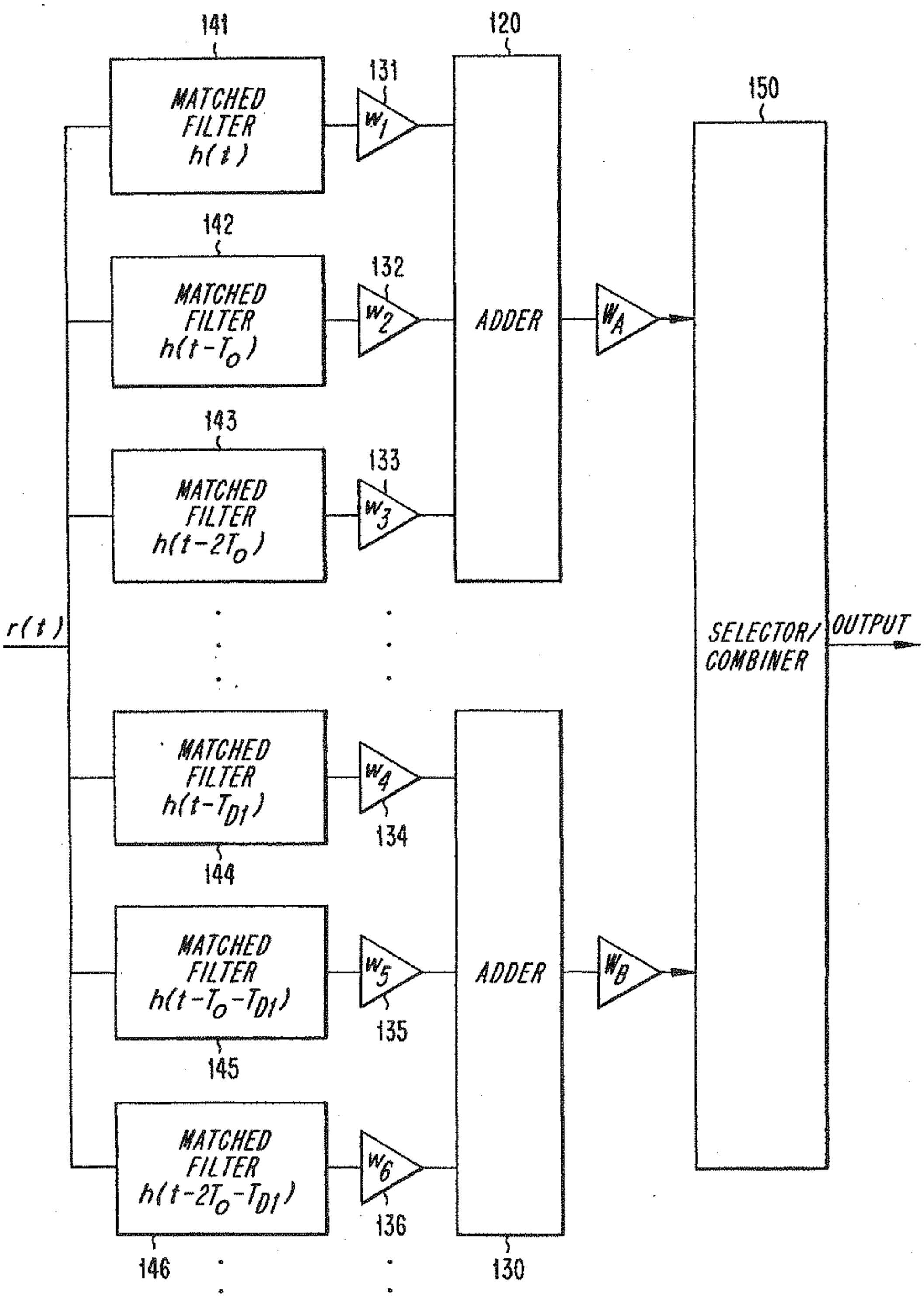
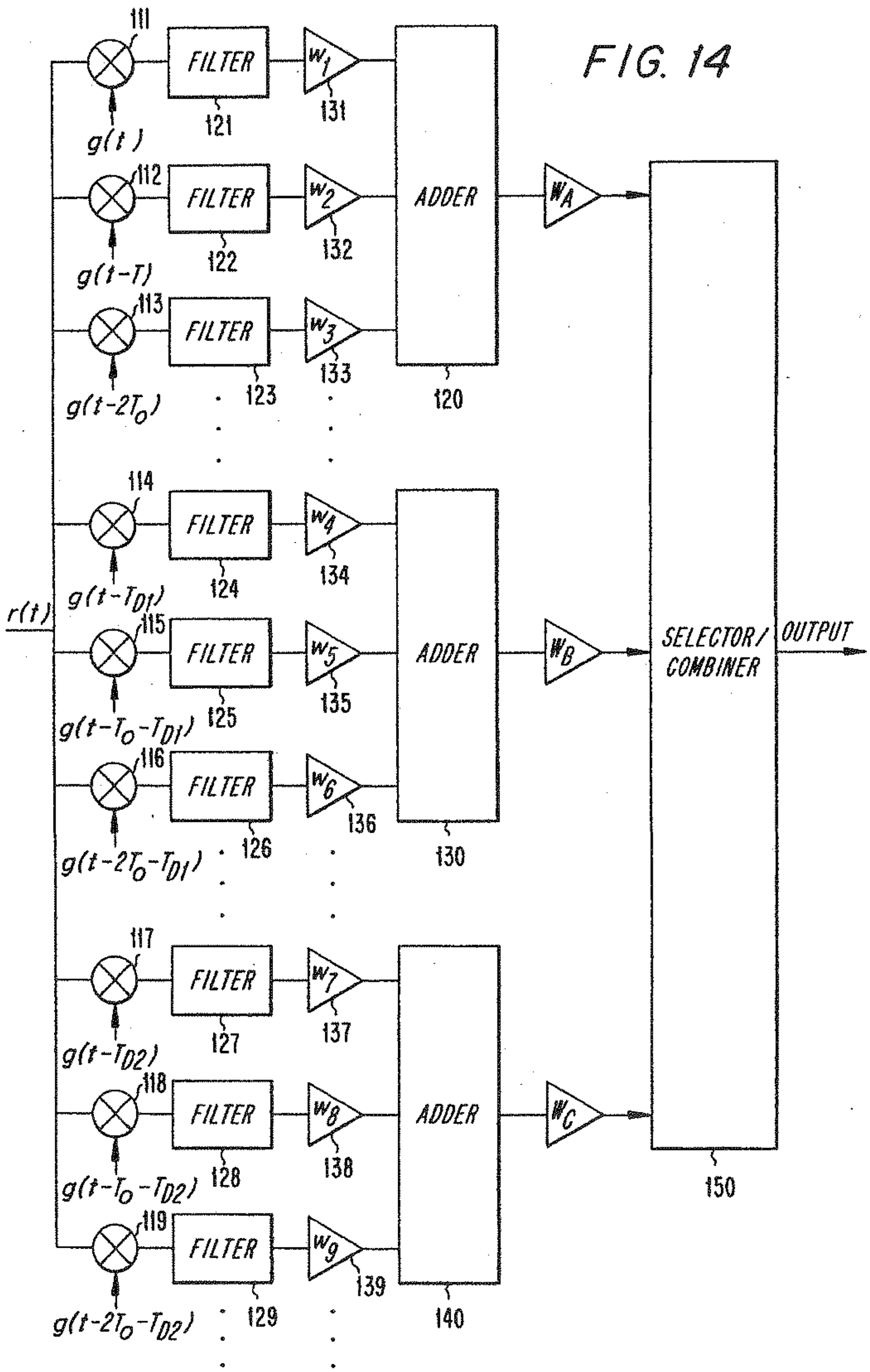


FIG. 13

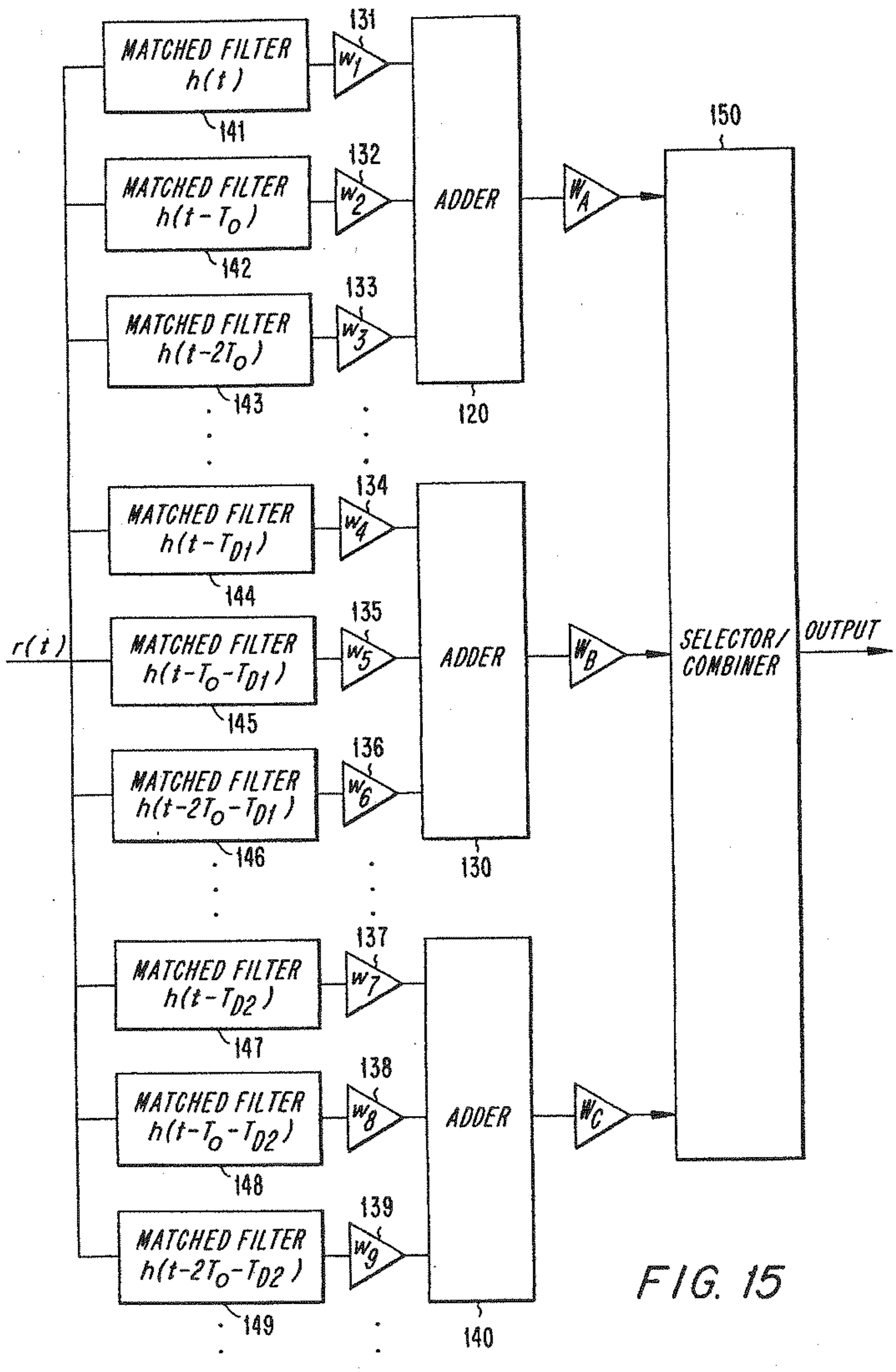


141
120
131
150
MATCHED FILTER h(t)
W_1
142
132
MATCHED FILTER h(t-T_O)
W_2
ADDER
W_A
143
133
MATCHED FILTER h(t-2T_O)
W_3
r(t)
SELECTOR/ COMBINER
OUTPUT
MATCHED FILTER h(t-T_{D1})
W_4
134
144
MATCHED FILTER h(t-T_O-T_{D1})
W_5
ADDER
W_B
135
145
MATCHED FILTER h(t-2T_O-T_{D1})
W_6
136
146
130

FIG. 14



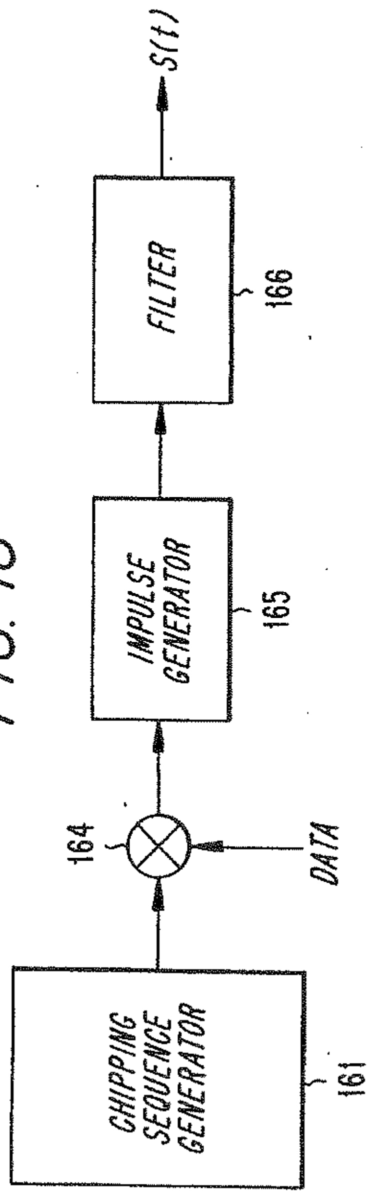
r(t)
111
112
113
114
115
116
117
118
119
g(t)
g(t-T)
g(t-2T0)
g(t-TD1)
g(t-T0-TD1)
g(t-2T0-TD1)
g(t-TD2)
g(t-T0-TD2)
g(t-2T0-TD2)
FILTER
121
122
123
124
125
126
127
128
129
W1
W2
W3
W4
W5
W6
W7
W8
W9
131
132
133
134
135
136
137
138
139
ADDER
120
130
140
WA
WB
WC
SELECTOR/
COMBINER
150
OUTPUT



MATCHED FILTER h(t)
141
131
W1
MATCHED FILTER h(t-T0)
142
132
W2
MATCHED FILTER h(t-2T0)
143
133
W3
ADDER
120
WA
150
MATCHED FILTER h(t-TD1)
144
134
W4
MATCHED FILTER h(t-T0-TD1)
145
135
W5
MATCHED FILTER h(t-2T0-TD1)
146
136
W6
ADDER
130
WB
r(t)
SELECTOR/ COMBINER
OUTPUT
MATCHED FILTER h(t-TD2)
147
137
W7
MATCHED FILTER h(t-T0-TD2)
148
138
W8
MATCHED FILTER h(t-2T0-TD2)
149
139
W9
ADDER
140
WC

FIG. 15

FIG. 16


CHIPPING SEQUENCE GENERATOR
161
164
DATA
IMPULSE GENERATOR
165
FILTER
166
S(t)

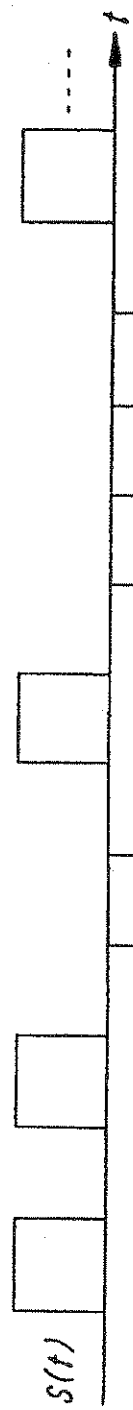
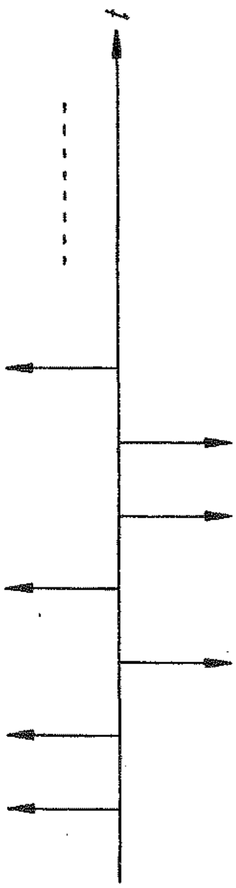

S(t)
t

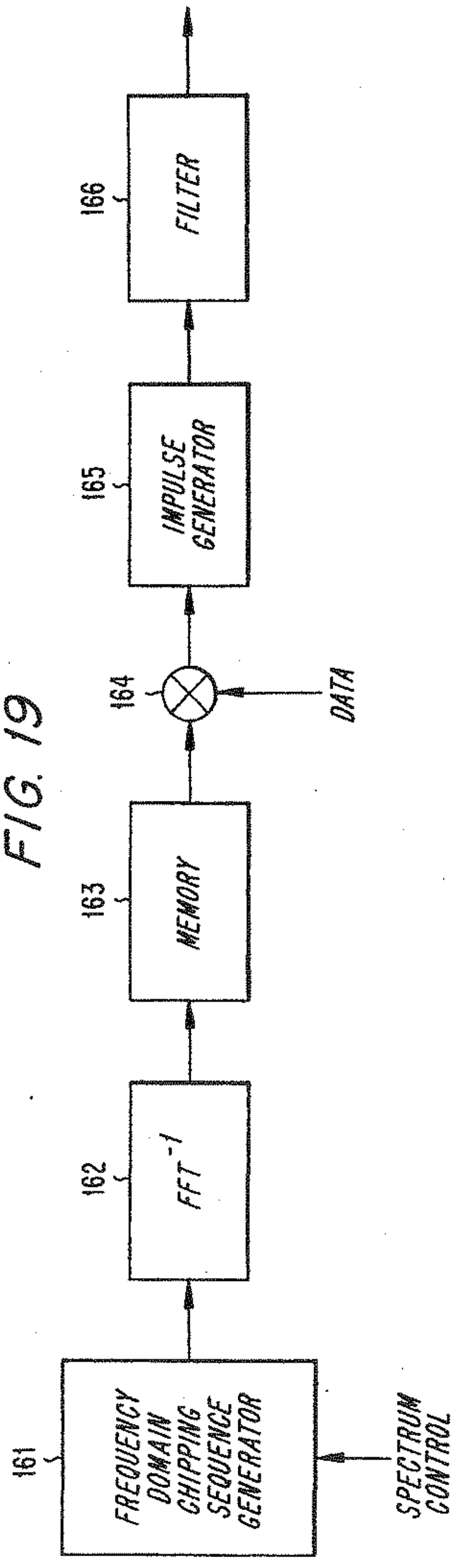
FIG. 17

FIG. 18



t

FIG. 19



161
FREQUENCY DOMAIN CHIPPING SEQUENCE GENERATOR
SPECTRUM CONTROL
162
FFT^-1
163
MEMORY
164
DATA
165
IMPULSE GENERATOR
166
FILTER

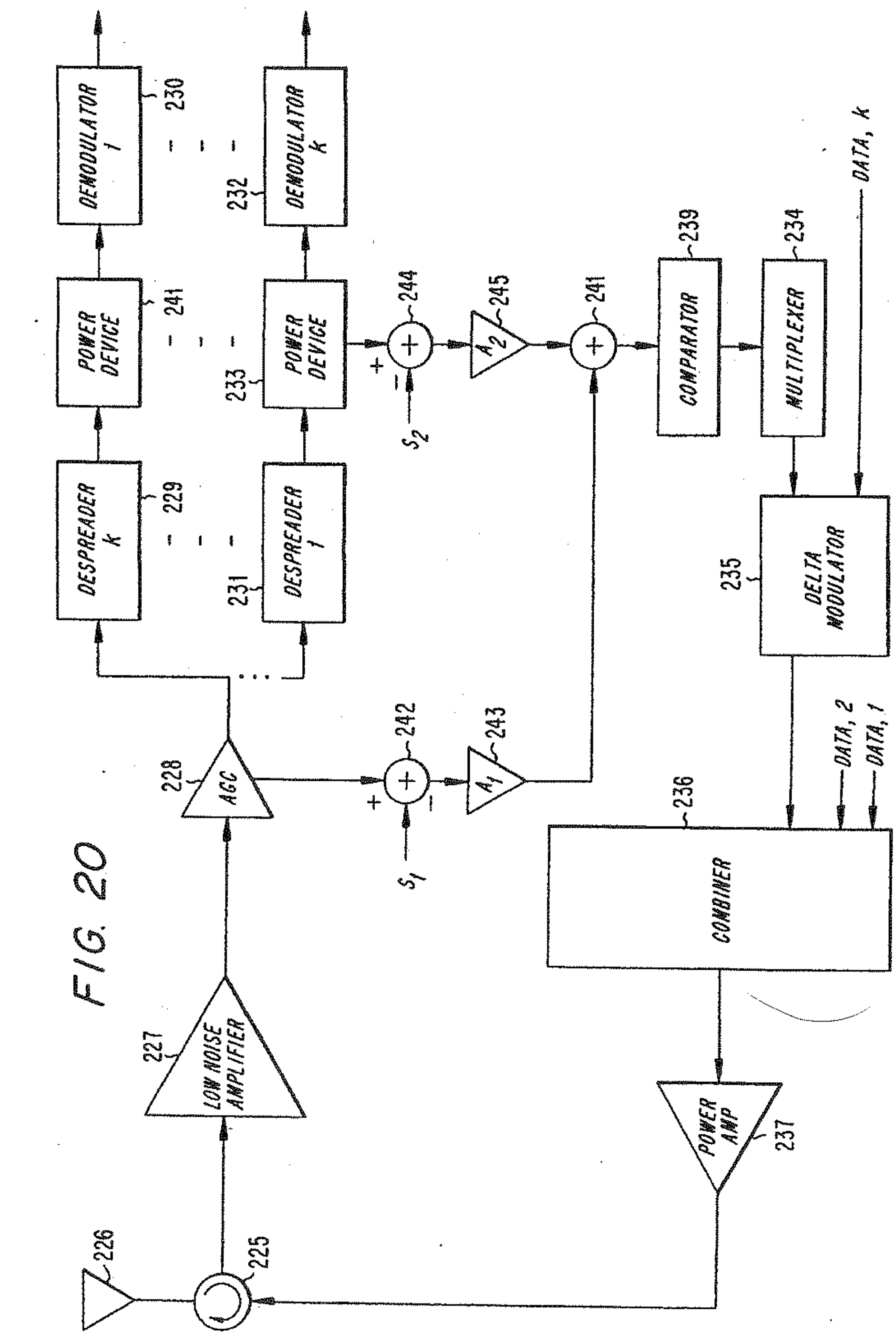

DEMODULATOR 1
230
DEMODULATOR k
232
POWER DEVICE
241
POWER DEVICE
233
DESPREADER k
229
DESPREADER 1
231
244
S_2
A_2
245
241
COMPARATOR
239
MULTIPLEXER
234
DATA, k
DELTA MODULATOR
235
AGC
228
242
S_1
A_1
243
DATA, 2
DATA, 1
236
COMBINER
LOW NOISE AMPLIFIER
227
POWER AMP
237
226
225

FIG. 20

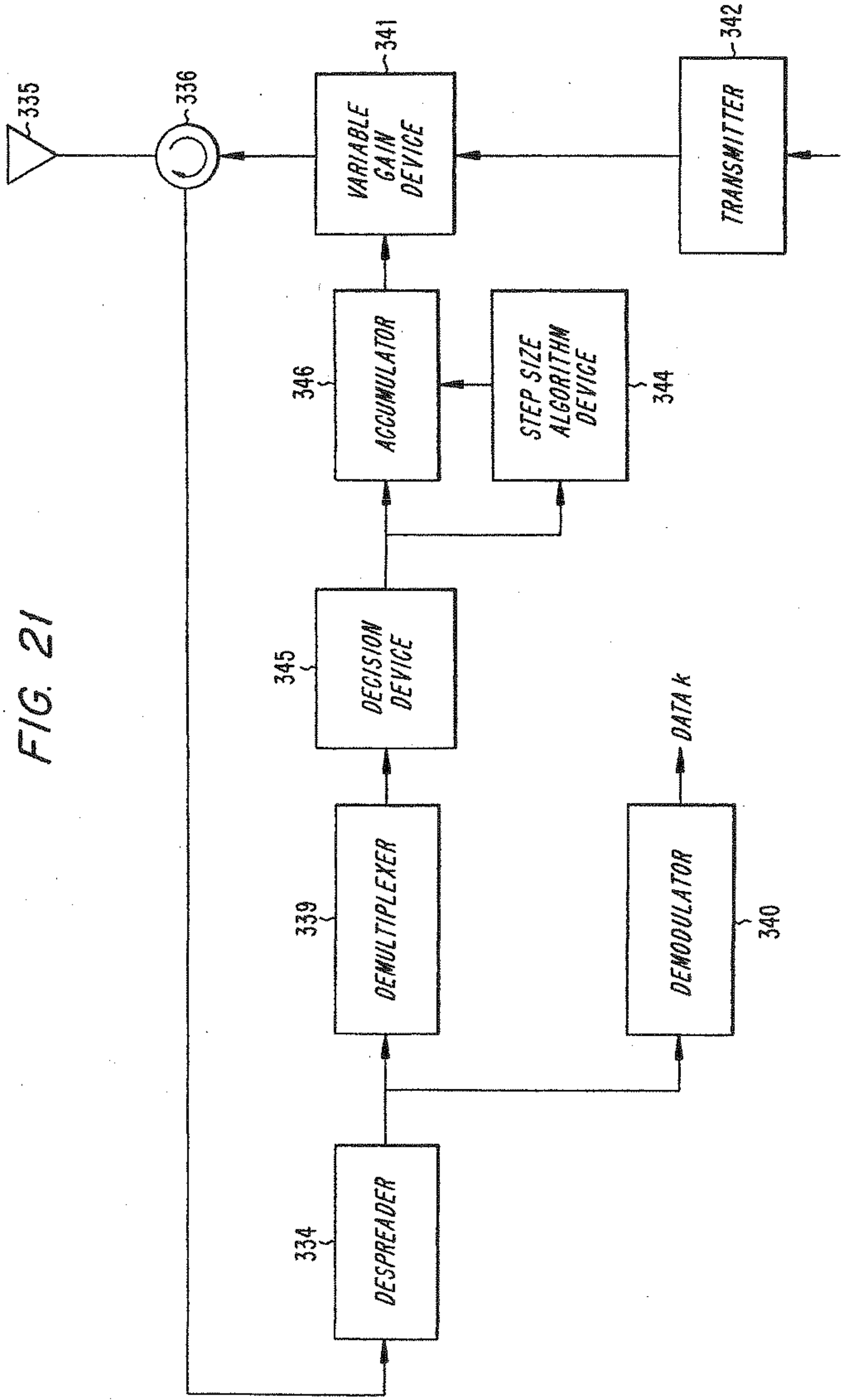
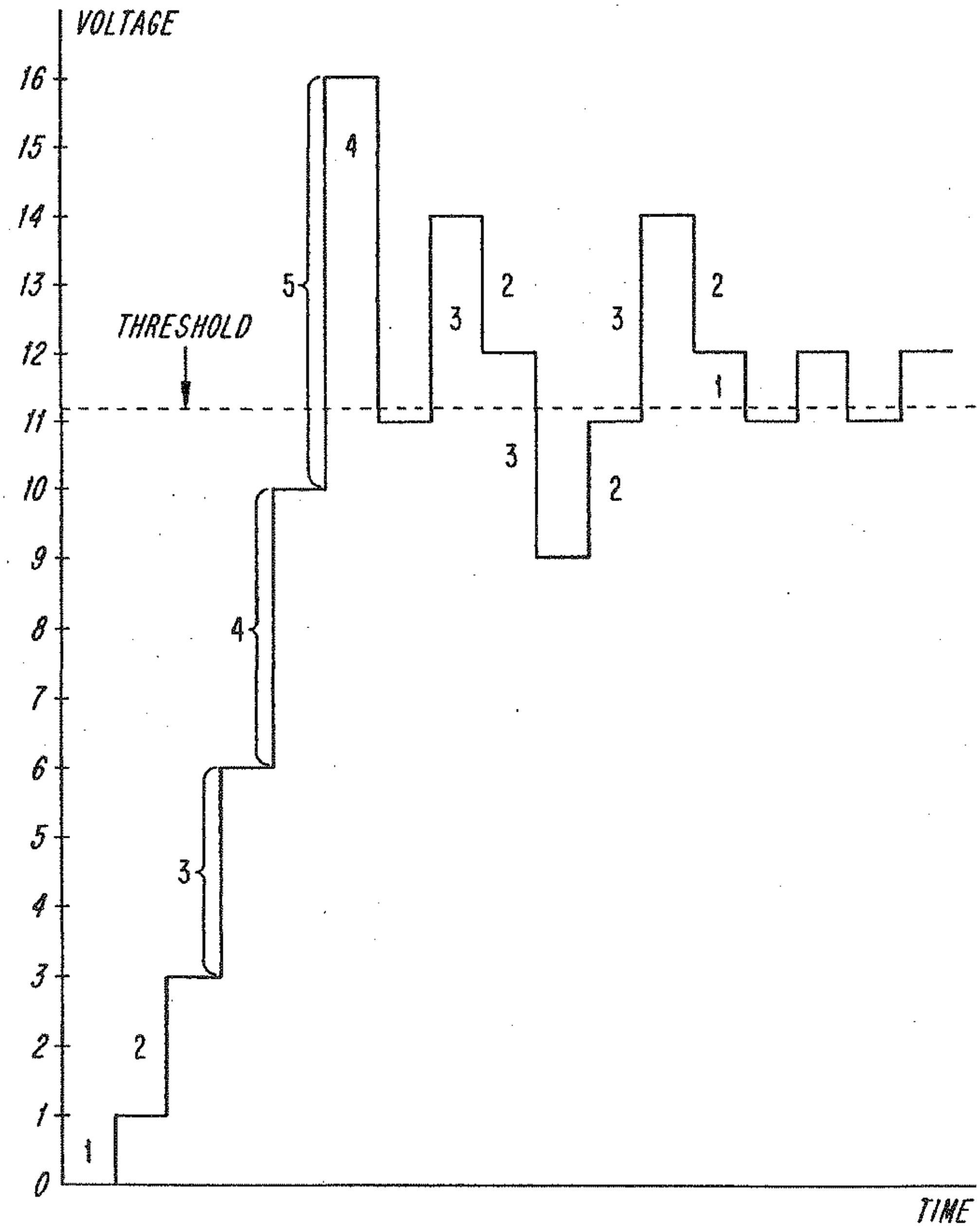

335
336
VARIABLE GAIN DEVICE
341
TRANSMITTER
342
ACCUMULATOR
346
STEP SIZE ALGORITHM DEVICE
344
DECISION DEVICE
345
DATA k
DEMULTIPLEXER
339
DEMODULATOR
340
DESPREADER
334

FIG. 21

FIG. 22



VOLTAGE
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
THRESHOLD
1
2
3
4
5
4
3
2
3
2
3
2
1
TIME

FIG. 23

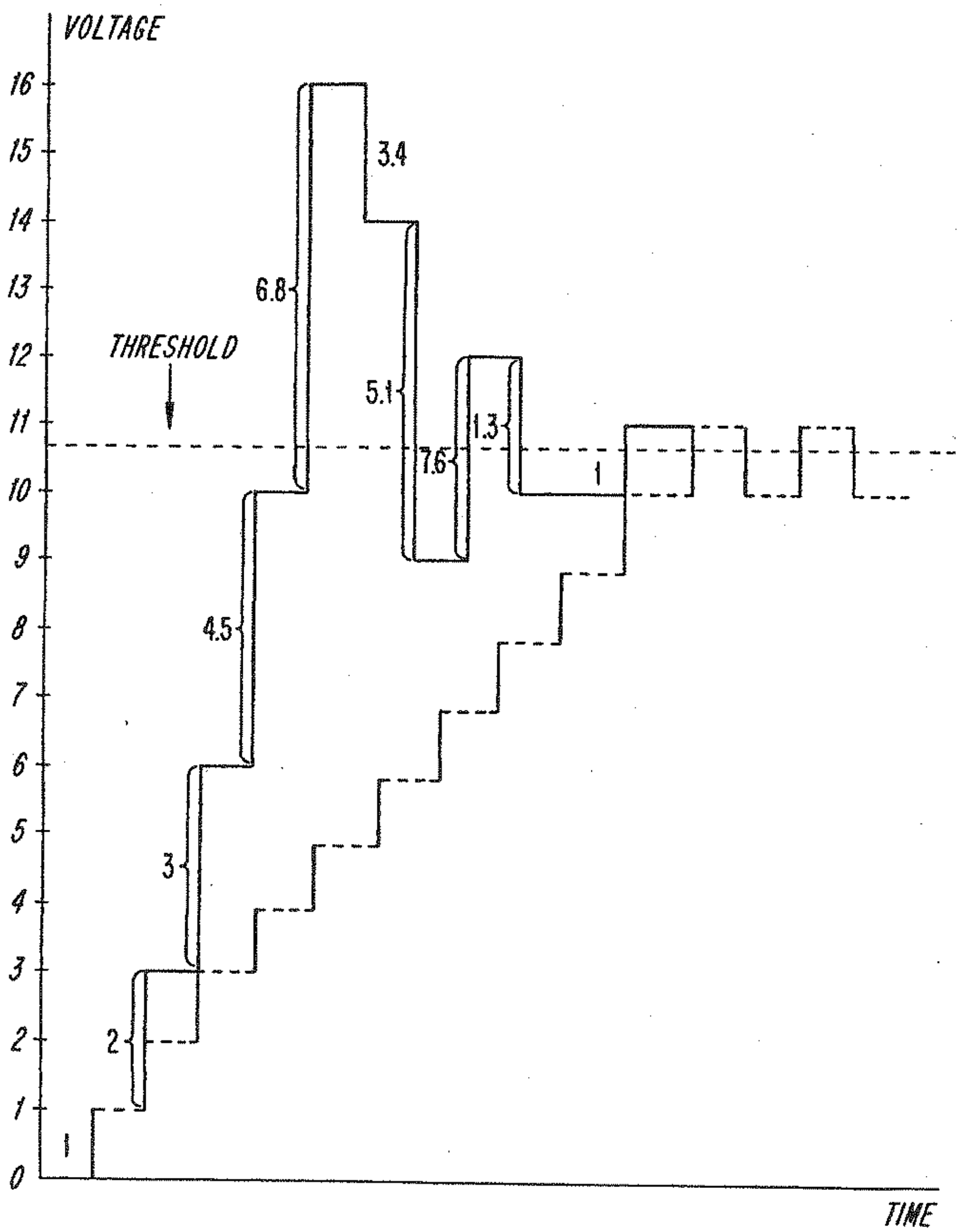

VOLTAGE
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
THRESHOLD
6.8
3.4
5.1
7.6
1.3
1
4.5
3
2
1
TIME

FIG. 24

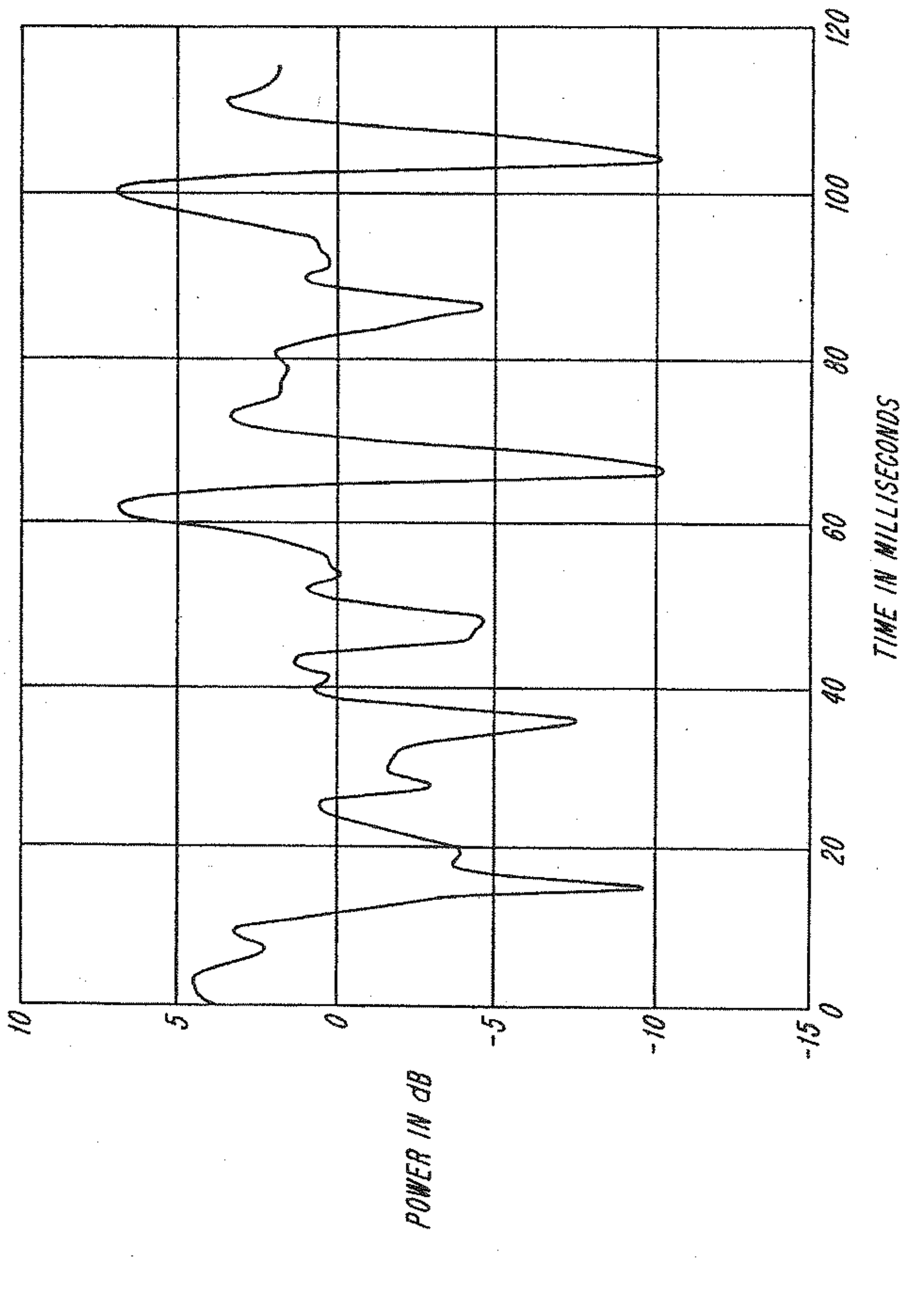

10
5
0
-5
-10
-15
POWER IN dB
0
20
40
60
80
100
120
TIME IN MILLISECONDS

FIG. 25

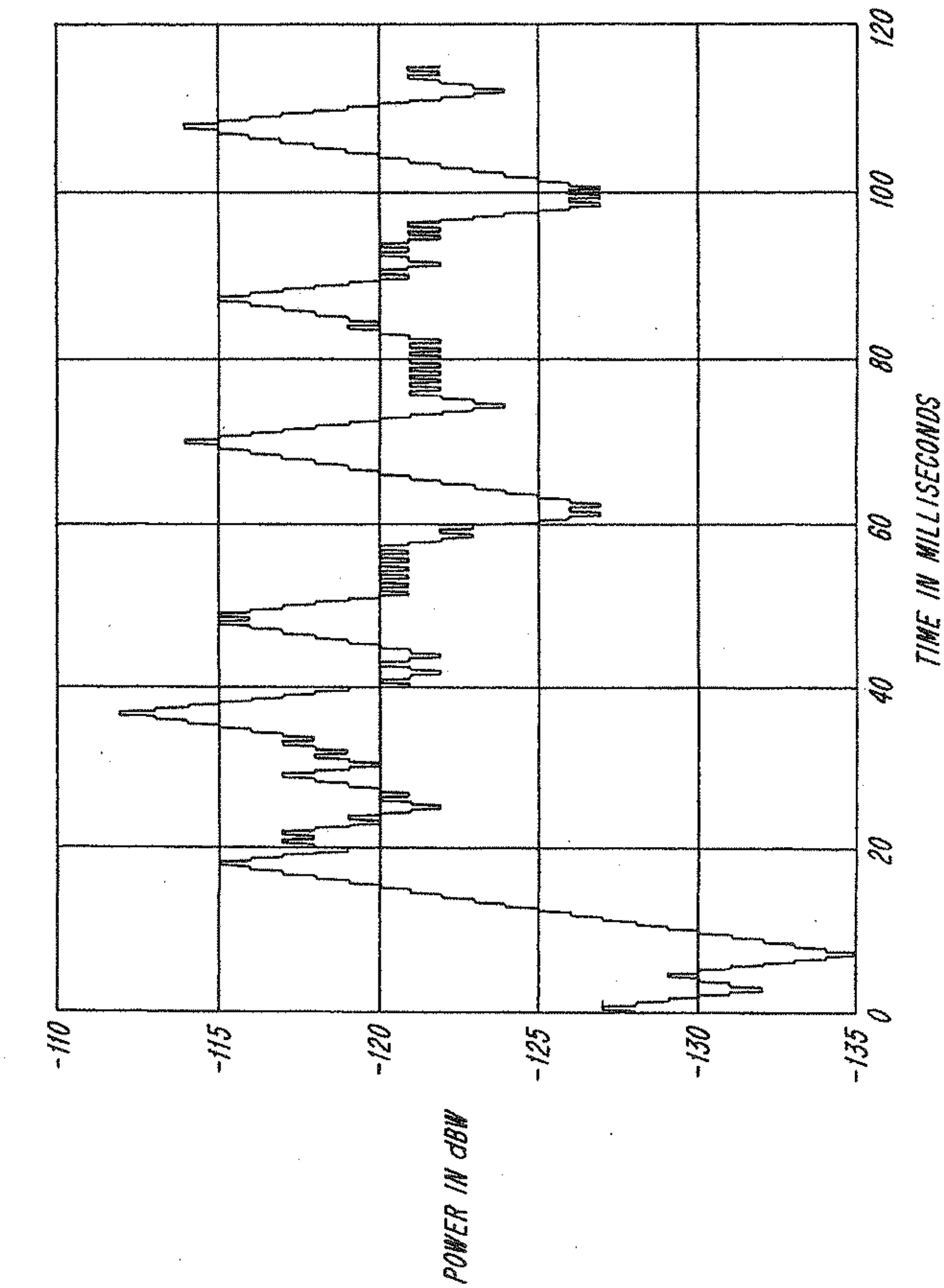

-110
-115
-120
-125
-130
-135
POWER IN dBW
0
20
40
60
80
100
120
TIME IN MILLISECONDS

FIG. 26

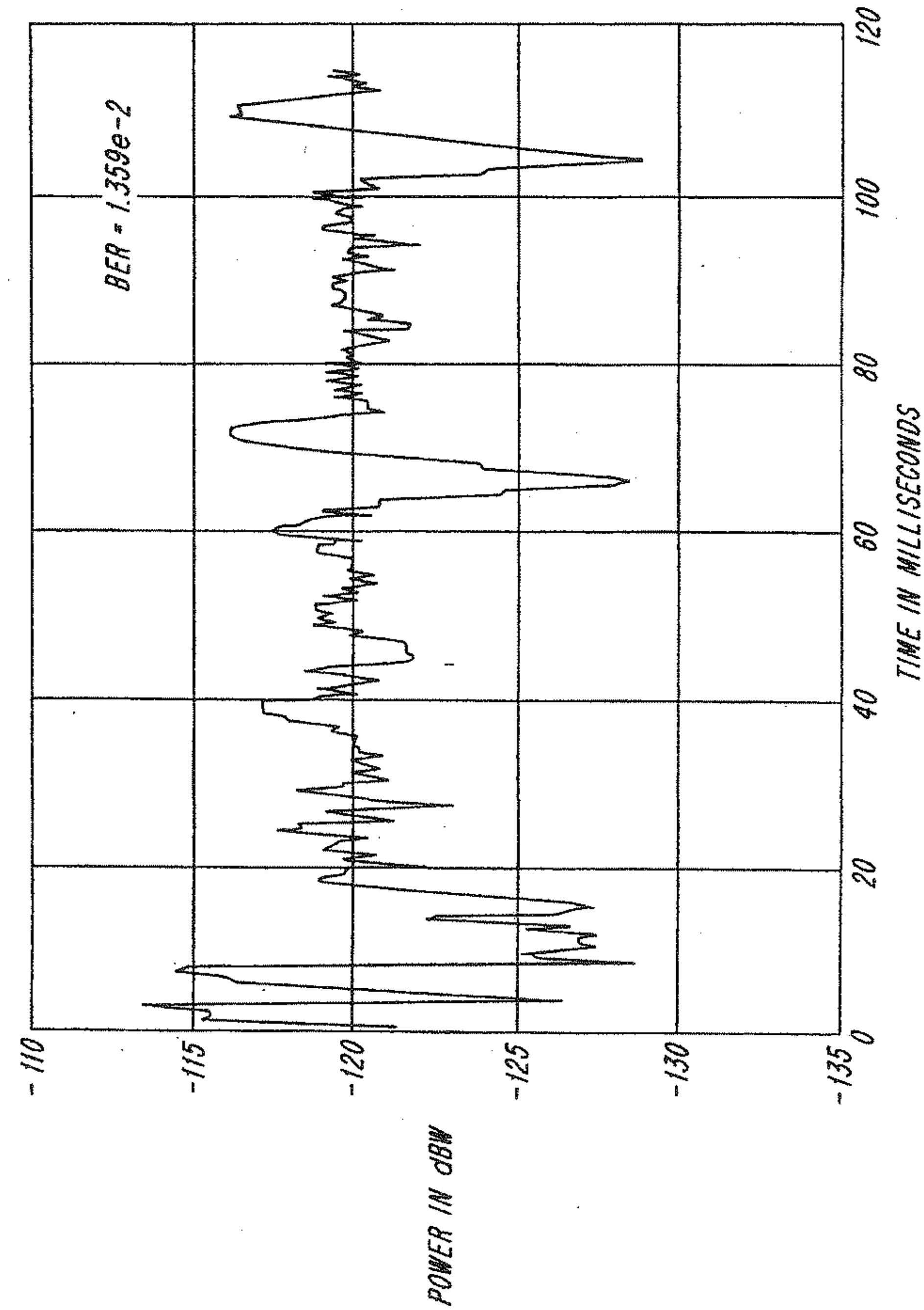
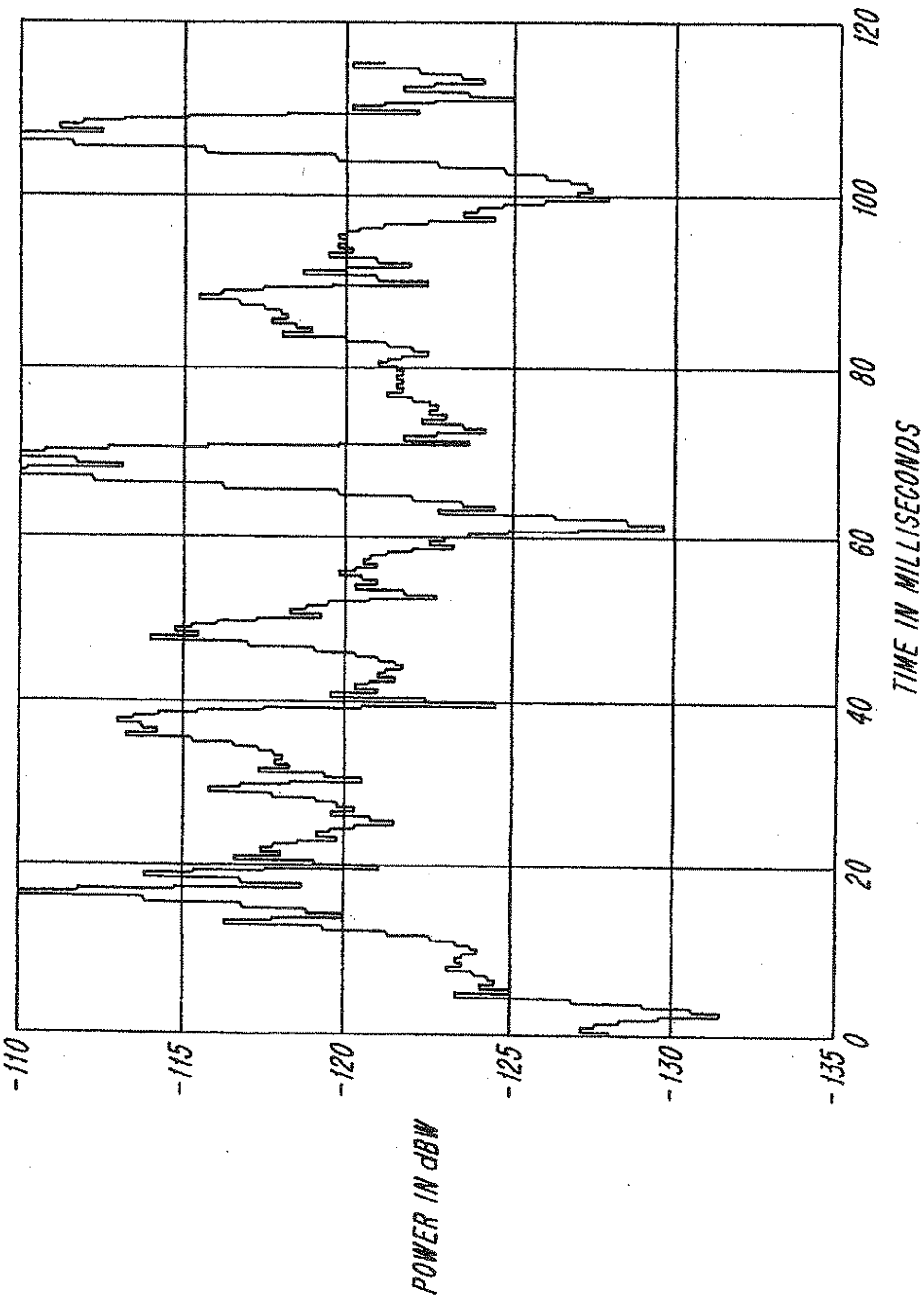
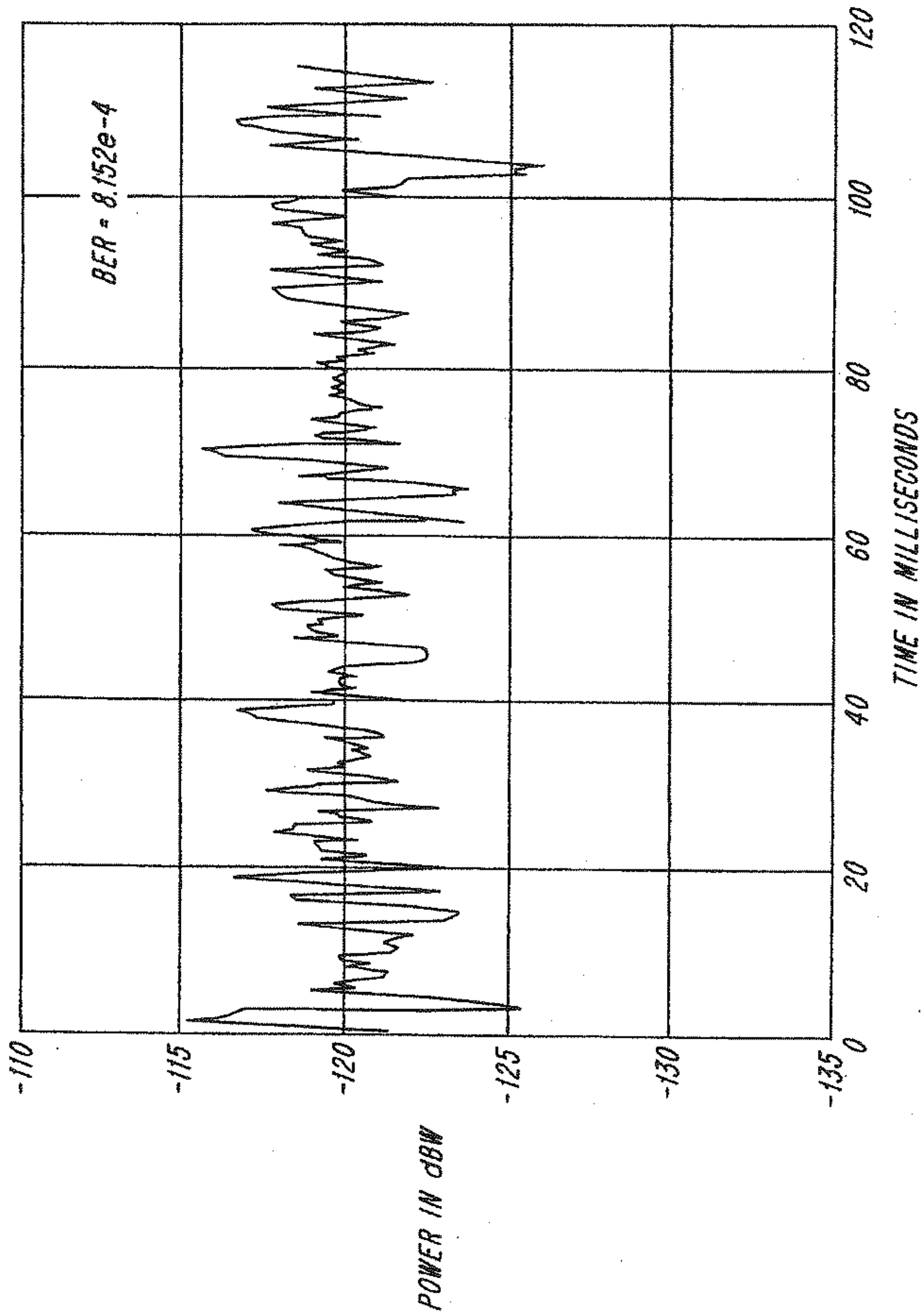

BER = 1.359e-2
-110
-115
-120
-125
-130
-135
POWER IN dBW
0
20
40
60
80
100
120
TIME IN MILLISECONDS

FIG. 27



-110
-115
-120
-125
-130
-135
POWER IN dBW
0
20
40
60
80
100
120
TIME IN MILLISECONDS

FIG. 28


BER = 8.152e-4
-110
-115
-120
-125
-130
-135
POWER IN dBW
0
20
40
60
80
100
120
TIME IN MILLISECONDS

SPREAD SPECTRUM ADAPTIVE POWER CONTROL SYSTEM AND METHOD

BACKGROUND OF THE INVENTION

This invention relates to spread-spectrum communications, and more particularly to a multipath processor, variable bandwidth device, and power control system.

DESCRIPTION OF THE RELEVANT ART

Spread-spectrum modulation provides means for communicating in which a spread-spectrum signal occupies a bandwidth in excess of the minimum bandwidth necessary to send the same information. The band spread is accomplished by modulating an information-data signal with a chipping-sequence signal which is independent of an information-data signal. The information-data signal may come from a data device such as a computer, or an analog device which outputs an analog signal which has been digitized to an information-data signal, such as voice or video. The chipping-sequence signal is generated by a chip-code where the time duration, T_c, of each chip is substantially less than a data bit or data symbol. A synchronized reception of the information-data signal with the chipping-sequence signal at a receiver is used for despreading the spread-spectrum signal and subsequent recovery of data from the spread-spectrum signal.

Spread-spectrum modulation offers many advantages as a communications system for an office or urban environment. These advantages include reducing intentional and unintentional interference, combating multipath problems, and providing multiple access to a communications system shared by multiple users. Commercially, these applications include, but are not limited to, local area networks for computers and personal communications networks for telephone, as well as other data applications.

A cellular communications network, using spread-spectrum modulation for communicating between a base station and a multiplicity of users, requires control of the power level of a particular mobile user station. Within a particular cell, a mobile station near the base station of the cell may be required to transmit with a power level less than that required when the mobile station is near an outer perimeter of the cell. This adjustment in power level is done to ensure a constant power level is received at the base station from each mobile station.

In a first geographical region, such as an urban environment, the cellular architecture may have small cells in which the respective base stations are close to each other, requiring a low power level from each mobile user. In a second geographical region, such as a rural environment, the cellular architecture may have large cells in which the respective base stations are spread apart, requiring a relatively high power level from each mobile user. A mobile user who moves from the first geographical region to the second geographical region typically adjusts the power level of his transmitter in order to meet the requirements of a particular geographic region. If such adjustments were not made, a mobile user traveling from a sparsely populated region with larger cells, using the relatively higher power level with his spread-spectrum transmitter, to a densely populated region with many small cells may, without reducing the original power level of his spread-spectrum transmitter, cause undesirable interference within the smaller cell into which he has traveled and/or to adjacent cells. Also, if a mobile user moves behind a building and has his signal to the base

station blocked by the building, then the mobile user's power level should be increased. These adjustments must be made quickly, with high dynamic range and in a manner to ensure an almost constant received power level with low root mean square error and peak deviations from the constant level.

Accordingly, there is a need to have a spread-spectrum system and method for automatically controlling a mobile user's spread-spectrum transmitter power level when operating in a cellular communications network.

SUMMARY OF THE INVENTION

A general object of the invention is high capacity communications, due to lower multipath fading and total equivalent bandwidth and data rate.

A second general object of the invention is a spread spectrum transmitter having variable and/or adjustable signal bandwidth capabilities.

Another general object of the invention is a system and method which results in maximization of user density within a cell domain while minimizing mobile user transmitted power. A further object of the invention is to provide an apparatus and method which controls the power level of a mobile station so that the power level received at the base station of each cell is the same for each mobile station.

Another object of the invention is to provide a system and method for automatically and adaptively controlling the power level of a mobile user in a cellular communications network.

A further object of the invention is to provide a spread-spectrum system and method which allows operating a spread-spectrum transmitter in different geographic regions, wherein each geographic region has a multiplicity of cells, and wherein cells within a geographic region may have different size cells and transmitter power requirements.

In a multipath environment, a spread spectrum signal reflects from multiple surfaces, such as buildings, and is assumed to generate a multiplicity of spread-spectrum signals. The multiplicity of spread-spectrum signals typically appear in a plurality of groups of spread-spectrum signals, with each group of spread-spectrum signals having a plurality of spread spectrum signals. The plurality of groups of spread-spectrum signals are a result of the spread-spectrum signal reflecting in a multipath environment.

A multipath processor for tracking a spread-spectrum signal arriving in a plurality of groups is provided. The multipath processor includes a first plurality of correlators, a second plurality of correlators, a first adder, a second adder, and a selector device or a combiner device. The first adder is coupled between the first plurality of correlators and the selector device or the combiner device. The second adder is coupled between the second plurality of correlators and the selector device or the combiner device.

The first plurality of correlators despreads a first plurality of spread-spectrum signals within a first group to generate a first plurality of despread signals. The first adder adds or combines the first plurality of despread signals to generate a first combined-despread signal.

The second plurality of correlators despreads a second plurality of spread-spectrum signals within a second group to generate a second plurality of despread signals. The second adder adds or combines the second plurality of despread signals to generate a second combined-despread signal.

The selector device selects either the first combined-despread signal or the second combined-despread signal. The selected combined-despread signal is outputted from the decision device as an output-despread signal. Alternatively, the combiner device may combine or add the first combined-despread signal with the second combined-despread signal to generate the output-despread signal.

The present invention also includes a variable-bandwidth spread-spectrum device for use with a spread-spectrum transmitter. The variable-bandwidth spread-spectrum device generates a spread-spectrum signal having a spread bandwidth. The variable-bandwidth spread-spectrum device uses a chipping-sequence signal having a chipping rate, with the chipping rate being less than the spread bandwidth. The variable-bandwidth spread-spectrum device includes a chipping-sequence generator, spread-spectrum processing means, an impulse generator, and a filter. The spread-spectrum processing means is coupled to the chipping-sequence generator. The impulse generator is coupled to the spread-spectrum processing means. The filter is coupled to the impulse generator.

The chipping-sequence generator generates the chipping-sequence signal with the chipping rate. The spread-spectrum processing means processes a data signal with the chipping-sequence signal to generate a spread-data signal. The impulse generator, responsive to each chip in the spread-data signal, generates an impulse signal. The filter filters a spectrum of each impulse signal with the spread bandwidth.

The spread-spectrum processing means may be embodied as an EXCLUSIVE-OR gate, a product device, or other device as is well known in the art for spread-spectrum processing data signals with chipping-sequence signals. The filter may include a variable bandwidth filter. The variable bandwidth filter may be used for varying or adjusting the spread bandwidth of the spectrum for each impulse signal. Accordingly, a spread spectrum signal may be designed having the bandwidth of choice, based on the bandwidth of the variable-bandwidth filter. The bandwidth may be variable, or adjustable, as would be required for particular system requirements. As used in this patent, a variable bandwidth is one that is able to vary according to time conditions or other requirements in a particular system. An adjustable bandwidth would be similar to a variable bandwidth, but is used to refer to a bandwidth which may be adjusted to remain at a chosen setting.

A system for adaptive-power control (APC) of a spread-spectrum transmitter is also provided. A plurality of mobile stations operate in a cellular-communications network using spread-spectrum modulation. A mobile station transmits a first spread-spectrum signal. The base station transmits a second spread-spectrum signal.

The base station includes automatic gain control (AGC) means, base-correlator means, comparator means, power means, transmitter means, and an antenna. The base-correlator means is coupled to the AGC means. The power means is coupled to the base-correlator means and to the comparator means. The comparator means is coupled to the power means. The antenna is coupled to the transmitter means.

Each mobile station includes despreading means and variable-gain means.

A received signal is defined herein to include the first spread-spectrum signal and an interfering signal. The interfering signal is defined herein to include noise and/or other spread-spectrum signals and/or other undesirable signals which are coexistent in frequency with the first spread-spectrum signal.

For each received signal, the AGC means generates an AGC-output signal. The base-correlator means despreads the AGC-output signal. The power means processes the despread-AGC-output signal and generates a received-power level. The comparator means generates a power-command signal by comparing the received-power level to a threshold level. The power-command signal may be an analog or digital data signal, or a data signal multiplexed with information data bits. The transmitter means at the base station transmits the power-command signal as the second spread-spectrum signal or as a data signal multiplexed with the information data bits.

At each mobile station, the despreading means despreads the power-command signal from the second spread-spectrum signal as a power-adjust signal. The variable-gain means uses the power-adjust signal as a basis for adjusting a transmitter-power level of the first spread-spectrum signal transmitted from the mobile-station transmitter. The transmitter-power level may be adjusted linearly or nonlinearly.

The present invention also includes a method for automatic-power control of a spread-spectrum transmitter for a mobile station operating in a cellular-communications network using spread-spectrum modulation. A mobile station transmits a first spread-spectrum signal. The base station performs the steps of acquiring the first spread-spectrum signal transmitted from the mobile station, and detecting a received power level of the first spread-spectrum signal plus any interfering signal including noise. The steps also include generating an AGC-output signal from the received signal, and despreading the AGC-output signal. The despread AGC-output signal is processed to generate a received-power level. The method further includes comparing the received-power level to the threshold level to generate a power-command signal. The power-command signal is transmitted from the base station as part of the second spread-spectrum signal.

At the mobile station the method despreads the power-command signal from the second spread-spectrum signal, and adjusts a transmitter power level of the first spread-spectrum signal in response to the power-command signal.

Additional objects and advantages of the invention are set forth in part in the description which follows, and in part are obvious from the description, or may be learned by practice of the invention. The objects and advantages of the invention also may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate preferred embodiments of the invention, and together with the description serve to explain the principles of the invention.

FIG. 1 illustrates channel impulse response giving rise to several multipath signals;

FIG. 2 illustrates conditions leading to two groups of several multipath signals;

FIG. 3 is a block diagram of a multipath processor using two sets of correlators for despreading a spread-spectrum signal received as two groups of spread-spectrum signals;

FIG. 4 is a block diagram for generating chipping-sequence signals with delays;

FIG. 5 is a tapped-delay line model of a communications channel;

FIG. 6 is a block diagram of a correlator;

FIG. 7 is an auto correlation function diagram generated from the correlator of FIG. 6;

FIG. 8 is a block diagram for tracking a received signal;

FIG. 9 is a block diagram for combining a pilot signal from a received spread-spectrum signal;

FIG. 10 is a block diagram for tracking a pilot signal embedded in a pilot channel of a spread-spectrum signal;

FIG. 11 illustrates cross-correlation between a received signal and a referenced chipping-sequence signal, as a function of referenced delay;

FIG. 12 illustrates the center of gravity of the cross-correlation function of FIG. 11;

FIG. 13 is a block diagram of a multipath processor using two sets of matched filters for despreading a spread-spectrum signal received as two groups of spread-spectrum signals;

FIG. 14 is a block diagram of a multipath processor using three sets of correlators for despreading a spread-spectrum signal received as three groups of spread-spectrum signals;

FIG. 15 is a block diagram of a multipath processor using three sets of matched filters for despreading a spread-spectrum signal received as three groups of spread-spectrum signals;

FIG. 16 is a block diagram of a variable-bandwidth spread-spectrum device;

FIG. 17 illustrates chips of a spread-data signal;

FIG. 18 illustrates impulse signals corresponding to the chips of the spread-data signal of FIG. 17;

FIG. 19 is an alternative block diagram of the variable-bandwidth spread-spectrum device of FIG. 16;

FIG. 20 is a block diagram of a base station;

FIG. 21 is a block diagram of a mobile station;

FIG. 22 illustrates nonlinear power adjustment;

FIG. 23 illustrates linear and nonlinear power adjustment;

FIG. 24 illustrates fades during transmission for multiple signals of equivalent power received at a base station;

FIG. 25 illustrates an adaptive power control signal of broadcast power for a fixed step algorithm;

FIG. 26 illustrates despread output power for a fixed step algorithm;

FIG. 27 illustrates an adaptive power control signal of broadcast power for a variable step algorithm; and

FIG. 28 illustrates despread output power for a variable step algorithm.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference now is made in detail to the present preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings, wherein like reference numerals indicate like elements throughout the several views.

Multipath Processor

In a multipath environment, a signal reflects from several buildings or other structures. The multiple reflections from the several buildings can result in several signals, or several groups of signals, arriving at a receiver. FIG. 1 illustrates a signal arriving in time as several signals. FIG. 2 illustrates a signal arriving in time as two groups of several signals. The multiple signals arriving at the receiver usually do not arrive with a uniform spread over time. Thus, in a multipath environment, a received signal r(t) may include two or more groups of spread-spectrum signals.

In the multipath environment, a spread-spectrum signal is assumed to generate a plurality of groups of spread-spectrum signals, with each group having a plurality of spread-spectrum signals. The plurality of groups is the result of the spread-spectrum signal reflecting in a multipath environment. As a means of responding to and dealing with this plurality of groups, the multipath processor is an improvement to a spread-spectrum receiver system.

In the exemplary arrangement shown in FIG. 3, a multipath processor for tracking a spread-spectrum signal is shown. The multipath processor is used as part of a spread-spectrum receiver system.

The multipath processor includes first despreading means, second despreading means, first combining means, second combining means, and selecting means or output-combining means. The first combining means is coupled between the first despreading means and the selecting means or the output-combining signal. The second combining means is coupled between the second despreading means and the selecting means or the output-combining means.

The first despreading means despreads a received signal having a first plurality of spread-spectrum signals within a first group. The first despreading means thus generates a first plurality of despread signals. The first combining means combines, or adds together, the first plurality of despread signals to generate a first combined-despread signal.

The second despreading means despreads the received signal having a second plurality of spread-spectrum signals within a second group. The second despreading means thereby generates a second plurality of despread signals. The second combining means combines, or adds together, the second plurality of despread signals as a second combined-despread signal.

The selecting means selects either the first combined-despread signal or the second combined-despread signal. The selected combined-despread signal is outputted from the selecting means as an output-despread signal. The selecting means may operate responsive to the stronger signal strength of the first combined-despread signal and the second combined-despread signal, least mean square error, a maximum likelihood, or other selection criteria. Alternatively, using output-combining means in place of selecting means, the outputs of the first combining means and the second combining means may be coherently combined or added together, after suitable weighting.

As shown in FIG. 3, the first despreading means may include a first plurality of correlators for despreading, respectively, the first plurality of spread-spectrum signals. The first plurality of correlators is illustrated, by way of example, as first multiplier **111**, second multiplier **112**, third multiplier **113**, first filter **121**, second filter **122**, third filter **123**, first chipping-sequence signal g(t), second chipping-sequence signal $g(t-T_o)$, and third chipping-sequence signal $g(t-2T_o)$. The second chipping-sequence signal $g(t-T_o)$ and the third chipping-sequence signal $g(t-2T_o)$ are the same as the first chipping-sequence signal g(t), but delayed by time T_o and time $2T_o$, respectively. The delay between each chipping-sequence signal, preferably, is a fixed delay T_o.

At the input is received signal r(t). The first multiplier **111** is coupled between the input and the first filter **121**, and to a source of the first chipping-sequence signal g(t). The second multiplier **112** is coupled between the input and the

second filter 122, and to a source of the second chipping-sequence signal $g(t-T_o)$. The third multiplier 113 is coupled between the input and the third filter 123, and to a source of the third chipping-sequence signal $g(t-2T_o)$. The outputs of the first filter 121, the second filter 122 and the third filter 123 are coupled to the first adder 120.

Circuitry and apparatus are well known in the art for generating chipping-sequence signals with various delays. Referring to FIG. 4, a chipping-sequence generator 401 is coupled to a voltage-controlled oscillator 402, and a plurality of delay devices 403, 404, 405, 406. The voltage-controlled oscillator receives a group-delay signal. The group-delay signal corresponds to the time delay that the group of chipping-sequence signals used for despreading a particular group of received signals. The voltage-controlled oscillator 402 generates an oscillator signal. The chipping-sequence generator 401 generates the first chipping-sequence signal g(t) from the oscillator signal, with an initial position of the first chipping-sequence signal g(t) determined from the group-delay signal. The first chipping-sequence signal g(t) is delayed by the plurality of delay devices 403, 404, 405, 406, to generate the second chipping-sequence signal $g(t-T_o)$, the third chipping-sequence signal $g(t-2T_o)$, the fourth chipping-sequence signal $(gt-3T_o)$, etc. Thus, the second chipping-sequence signal $g(t-T_o)$ and the third chipping-sequence signal $g(t-2T_o)$ may be generated as delayed versions of the first chipping-sequence signal g(t). Additionally, acquisition and tracking circuitry are part of the receiver circuit for acquiring a particular chipping-sequence signal embed-ded in a received spread-spectrum signal.

Optionally, the multipath processor of FIG. 3 may include first weighting device 131, second weighting device 132 and third weighting device 133. The first weighting device 131 is coupled to the output of the first filter 121, and a source of a first weighting signal W_1. The second weighting device 132 is coupled to the output of the second filter 122, and to a source of the second weighting signal W_2. The third weighting device 133 is coupled to the output of the third filter 123 and to a source of the third weighting signal W_3. The first weighting signal W_1, the second weighting signal W_2 and the third weighting signal W_3 are optional, and may be preset within the first weighting device 131, the second weighting device 132 and the third weighting device 133, respectively. Alternatively, the first weighting signal W_1, the second weighting signal W_2, and the third weighting signal W_3 may be controlled by a processor or other control circuitry. The outputs of the first filter 121, the second filter 122, and the third filter 123 are coupled through the first weighting device 131, the second weighting device 132 and the third weighting device 133, respectively, to the first adder 120.

Similarly, the second despreading means may include a second plurality of correlators for despreading the second plurality of spread-spectrum signals. The second plurality of correlators is illustrated, by way of example, as fourth multiplier 114, fifth multiplier 115, sixth multiplier 116, fourth filter 124, fifth filter 125, sixth filter 126, fourth chipping-sequence signal $g(t-T_{D1})$, fifth chipping-sequence signal $g(t-T_o-T_{D1})$, and sixth chipping-sequence signal $g(t-2T_o-T_{D1})$. The fourth multiplier 114 is coupled between the input and the fourth filter 124, and a source of the fourth chipping-sequence signal $g(t-T_{D1})$. The fifth multiplier 115 is coupled between the input and the fifth filter 125 and a source of the fifth chipping-sequence signal $g(t-T_o-T_{D1})$. The sixth multiplier 116 is coupled between the input and the sixth filter 126, and a source of the sixth chipping-sequence signal $g(t-2T_o-T_{D1})$. The fourth chipping-sequence signal $g(t-T_{D1})$, the fifth chipping-sequence signal $g(t-T_o-T_{D1})$ and the sixth chipping-sequence signal $g(t-2T_o-T_{D1})$ are the same as the first chipping-sequence signal g(t), but delayed by time T_{D1}, time T_o+T_{D1}, and time $2T_o+T_{D1}$, respectively. The second plurality of correlators thereby generates the second plurality of despread signals. The outputs of the fourth filter 124, the fifth filter 125 and the sixth filter 126 are coupled to the second adder 130.

At the output of the fourth filter 124, the fifth filter 125, and the sixth filter 126, optionally, may be fourth weighting device 134, fifth weighting device 135, and sixth weighting device 136. The fourth weighting device 134, fifth weighting device 135, and sixth weighting device 136 are coupled to a source which generates fourth weighting signal W_4, fifth weighting signal W_5, and sixth weighting signal W_6, respectively. The fourth weighting signal W_4, the fifth weighting signal W_5, and the sixth weighting signal W_6 are optional, and may be preset within the fourth weighting device 134, the fifth weighting device 135, and the sixth weighting device 136, respectively. Alternatively, the fourth weighting signal W_4, the fifth weighting signal W_5, and the sixth weighting signal W_6 may be controlled by a processor or other control circuitry. The outputs of the fourth filter 124, fifth filter 125, and sixth filter 126 are coupled through the fourth weighting device 134, fifth weighting device, 135 and sixth weighting device 136, respectively, to the second adder 130. The output of the first adder 120 and the second adder 130 are coupled to the decision device 150. The decision device 150 may be a selector or a combiner.

The weighting devices may be embodied as an amplifier or attenuation circuits, which change the magnitude and phase. The amplifier or attenuation circuits may be implemented with analog devices or with digital circuitry. The amplifier circuit or attenuation circuit may be adjustable, with the gain of the amplifier circuit or attenuation circuit controlled by the weighting signal. The use of a weighting signal with a particular weighting device is optional. A particular weighting device may be designed with a fixed weight or a preset amount, such as a fixed amount of amplifier gain.

FIG. 5 is a tapped-delay-line model of a communications channel. A signal s(t) entering the communications channel passes through a plurality of delays 411, 412, 413, 414, modeled with time T_o. The signal s(t), for each delay, is attenuated 416, 417, 418 by a plurality of complex attenuation factors h^n and adder 419. The OUTPUT from the adder 419 is the output from the communications channel.

A given communications channel has a frequency response which is the Fourier transform of the impulse response.

$$H(f) = \sum_{i=1}^{N} a_i e^{-j2\pi f \tau_i}$$

where a_i represents the complex gains of the multipaths of the communications channel, and τ_i represents the delays of the multipaths of the communications channel.

Consider the communications-channel-frequency response, $H_c(f)$. The communications-channel-frequency response has a band of interest, B. Hereafter, this band of interest is fixed, and the communications-channel-frequency response $H_c(f)$ is the equivalent lowpass filter function. The communications-channel-frequency response expands in Fourier series as

$$H_c(f) = \Sigma\, h_n e^{-jn2\pi f/B}$$

where h_n represents Fourier coefficients. This is a tapped-delay-line model of the communications channel for which the receiver in FIG. 3 acts as a matched filter when $T_o=1/B$, and the weights W_n are set to the complex conjugate of the values h_n. That is, $W_n=h_n$.

Preferably, each correlator of the first plurality of correlators despreads with a chipping-sequence signal g(t) which has a time delay different from each time delay of each chipping-sequence signal used, respectively, with each of the other correlators of the first plurality of correlators. The first plurality of correlators uses chipping-sequence signals g(t), g(t-T_o), g(t-2T_o), where T_o is the time delay between chipping-sequence signals. The time delay T_o may be the same or different between each chipping-sequence signal. For illustrative purposes, time delay T_o is assumed to be the same.

Similarly, each correlator of the second plurality of correlators despreads with a chipping-sequence signal having a time delay different from each time delay of each other chipping-sequence signal used, respectively, with each of the other correlators of the second plurality of correlators. Also, each correlator of the second plurality of correlators despreads with a chipping-sequence signal having the time delay T_{D1} different from each time delay of each chipping-sequence signal used with each respective correlator of the first plurality of correlators. Thus, the second plurality of correlators uses chipping-sequence signals g(t-T_{D1}), g(t-T_o-T_{D1}), g(t-2T_o-T_{D1}), where time delay T_{D1} is the time delay between the first plurality of correlators and the second plurality of correlators. The time delay T_{D1} is also approximately the same time delay as between the first received group of spread-spectrum signals and the second received group of spread-spectrum signals.

FIG. 6 illustrates a correlator, where an input signal s(t) is multiplied by multiplier **674** by a delayed version of the input signal s(t-T). The product of the two signals is filtered by the filter **675**, and the output is the autocorrelation function R(T). The autocorrelation function R(T) for a square wave input signal s(t) is shown in FIG. 7. Over a chip time T_c, the correlation function R(T) is maximized when points A and B are equal in amplitude. A circuit which is well known in the art for performing this function is shown in FIG. 8. In FIG. 8, the despread signal s(t) is delayed by a half chip time $T_c/2$, and forwarded by half a chip time $T_c/2$. Each of the three signals are multiplied by the received signal r(t). The outputs of the delayed and forwarded multiplied signals are filtered, and then amplitude detected. The two filtered signals are combined by subtracting the delayed version from the forwarded version, and the difference or error signal is used to adjust the timing of the chipping-sequence signal used to despread signal s(t). Accordingly, if the delayed version were ahead of the forwarded version, the chipping-sequence signal for despread signal s(t) would be delayed. Likewise, if the forwarded version were ahead of the delayed version, then the chipping-sequence signal for despreading signal s(t) would be advanced. These techniques are well known in the art.

A similar technique is used for estimating a pilot signal from a received signal r(t), which has passed through a multipath environment. Referring to FIG. 9, the lower part of the diagram shows correlators corresponding to the correlators previously shown in FIG. 3. The upper part of the diagram shows the received signal processed by delayed versions of the pilot chipping-sequence signal $g_p(t)$. In FIG. 9, the received signal r(t) is multiplied by the pilot signal $g_p(t)$, and a plurality of delayed versions of the pilot signal $g_p(t-T_o), \ldots, g_p(t-kT_o)$ by a plurality of multipliers **661, 651, 641**. The output of the plurality of multipliers **661, 651, 641**, are each filtered by a plurality of filters **662, 652, 642**, respectively. The output of the plurality of filters **662, 652, 642** are multiplied by a second plurality of multipliers **663, 653, 643** and respectively filtered by a second plurality of filters **664, 654, 644**. The outputs of the second plurality of filters **664, 654, 644** are processed through a plurality of complex conjugate devices **665, 655, 645**. The outputs of the plurality of complex conjugate devices **665, 655, 645** are the plurality of weights W_1, W_2, W_k, respectively. The plurality of weights are multiplied by the output of the first plurality of filters **662, 652, 642**, by a third plurality of multipliers **666, 656, 646**, and then combined by the combiner **667**. At the output of the combiner **667** is a combined-despread-pilot signal.

Each of the second plurality of pilot filters **664, 654, 644** has a bandwidth which is approximately equal to the fading bandwidth. This bandwidth typically is very narrow, and may be on the order of several hundred Hertz.

Referring to FIG. 10, the output of the combiner **667** is multiplied by a fourth multiplier **668**, and passed through an imaginary device **669** for determining the imaginary component of the complex signal from the fourth multiplier **668**. The output of the imaginary device **669** passes through a loop filter **672** to a voltage controlled oscillator **673** or a numerically controlled oscillator (NCO). The output of the voltage controlled oscillator **673** passes to the fourth multiplier **668** and to each of the second plurality of multipliers **663, 653, 643**.

Referring to FIG. 11, the foregoing circuits can generate a cross-correlation function between the received signal and a referenced pilot-chipping signal as a function of referenced delay, or lag. As shown in FIG. 11, these points of cross-correlation can have a center of gravity. The center of gravity is determined when the left mass equals the right mass of the correlation function, as shown in FIG. 12. A circuit similar to that shown in FIG. 8, coupled to the output of the fourth multiplier **668**, can be used for aligning a chipping-sequence signal of the pilot channel.

As an alternative embodiment, as shown in FIG. 13, the first despreading means may include a first plurality of matched filters for despreading the received signal r(t) having the first plurality of spread-spectrum signals. At the output of the first plurality of matched filters is the first plurality of despread signals. Each matched filter of the first plurality of matched filters has an impulse response h(t), h(t-T_o), h(t-2T_o), etc., with a time delay T_o offset from the other matched filters. Referring to FIG. 13, by way of example, a first matched filter **141** is coupled between the input and through the first weighting device **131** to the first adder **120**. A second matched filter **142** is coupled between the input and through the second weighting device **132** to the first adder **120**. A third matched filter **143** is coupled between the input and through the third weighting device **133** to the first adder **120**. As mentioned previously, the first weighting device **131**, the second weighting device **132**, and the third weighting device **133** are optional. The first weighting device **131**, the second weighting device **132**, and the third weighting device **133** generally are connected to a source of the first weighting signal W_1, the second weighting signal W_2, and the third weighting signal W_3, respectively. The first plurality of matched filters generates the first plurality of despread signals.

Similarly, the second despreading means may include a second plurality of matched filters for despreading the

received signal r(t) having the second plurality of spread-spectrum signals. Accordingly, at the output of the second plurality of matched filters is the second plurality of despread signals. Each matched filter of the second plurality of matched filters has an impulse response, $h(t-T_{D1})$, $h(t-T_o-T_{D1})$, $h(t-2T_o-T_{D1})$, etc., with a time delay T_o offset from the other matched filters and with a time delay T_{D1}offset from the first plurality of matched filters. A fourth matched filter **144** is coupled between the input and through the fourth weighting device **134** to the second adder **130**. A fifth matched filter **145** is coupled between the input, and through the fifth weighting device **135** to the second adder **130**. A sixth matched filter **146** is coupled between the input and through the sixth weighting device **136** to the second adder **130**. As mentioned previously, the fourth weighting device **134**, the fifth weighting device **135**, and the sixth weighting device **136** are optional. The fourth weighting device **134**, the fifth weighting device **135**, and the sixth weighting device **136**, are coupled respectively to a source for generating the fourth weighting signal W_4, the fifth weighting signal W_5, and the sixth weighting signal W_6. Also, as with the correlator embodiment, the first adder **120** and the second adder **130** are coupled to the decision device **150**. The decision device **150** may be embodied as a selector or a combiner.

The present invention may further include despreading spread-spectrum signals located within a third group. Accordingly, the present invention may include third despreading means and third combining means. The third combining means is coupled between the third despreading means and the selecting means.

As shown in FIG. **14**, the third despreading means despreads the received signal r(t) received as a third plurality of spread-spectrum signals within a third group. Accordingly, the third despreading means generates a third plurality of despread signals. The third combining means combines the third plurality of despread signals as a third combined-despread signal. The selecting means selects one of the first combined-despread signal, the second combined-despread signal or the third combined-despread signal. The output of the selecting means is the output-despread signal.

As shown in FIG. **14**, the third despreading means may include a third plurality of correlators for despreading the third plurality of spread-spectrum signals. The third plurality of correlators is illustrated, by way of example, with seventh multiplier **117**, eighth multiplier **118**, ninth multiplier **119**, seventh filter **127**, eighth filter **128**, ninth filter **129**, and a source for generating the seventh chipping-sequence signal $g(t-T_{D2})$, the eighth chipping-sequence signal $g(t-T_o-T_{D2})$, and the ninth chipping-sequence signal $g(t-2T_o-T_{D2})$. The seventh multiplier **117** is coupled between the input and the seventh filter **127**. The eighth multiplier **118** is coupled between the input and the eighth filter **128**. The ninth multiplier **119** is coupled between the input and the ninth filter **129**. The seventh multiplier **117**, the eighth multiplier **118**, and the ninth multiplier **119**, are coupled to the source for generating the seventh chipping-sequence signal, the eighth chipping-sequence signal and the ninth chipping-sequence signal, respectively. Optionally, at the output of the seventh filter **127**, eighth filter **128**, and ninth filter **129**, may be seventh weighting device **137**, eighth weighting device **138**, and ninth weighting device **139**, respectively. Accordingly, the output of the seventh filter **127** is coupled through the seventh weighting device **137** to the third adder **140**. The output of the eighth filter **128** is coupled through the eighth weighting device **138** to the third adder **140**. The output of the ninth multiplier **129** is coupled through the ninth weighting device **139** to the third adder **140**. The third adder is coupled to the decision device **150**. At the output of the third plurality of correlators is the third plurality of despread signals, respectively.

Preferably, each correlator of the third plurality of correlators despreads with a chipping-sequence signal $g(t-T_{D2})$, $g(t-T_o-T_{D2})$, $g(t-2T_o-T_{D2})$ having a time delay T_o different from each time delay of each chipping-sequence signal used with other correlators of the third plurality of correlators. Also, each correlator of the third plurality of correlators despreads with a chipping-sequence signal having a time delay different from each time delay of each chipping-sequence signal used, respectively, with each correlator of the second plurality of correlators. Also, each correlator of the third plurality of correlators despreads with a chipping-sequence signal having a time delay $2T_D$ different from each chipping-sequence signal used with each correlator of the first plurality of correlators. Alternatively, the third despreading means may include, as shown in FIG. **15**, a third plurality of matched filters for despreading the third plurality of spread-spectrum signals. The third plurality of matched filters includes seventh matched filter **147**, eighth matched filter **148**, and ninth matched filter **149**. The seventh matched filter is coupled between the input and through the seventh weighting device **137** to the third adder **140**. The eighth matched filter **148** is coupled between the input and through the eighth weighting device **138** to the third adder **140**. The ninth matched filter **149** is coupled between the input and through the ninth weighting device **139** to the third adder **140**. The third adder **140** is coupled to the decision device **150**. At the output of the third plurality of matched filters is the third plurality of despread signals.

The present invention may include fourth despreading means and fourth combining means, with the fourth combining means coupled between the fourth despreading means and the selecting means. The fourth despreading means would despread a fourth plurality of spread-spectrum signals within a fourth group. The output of the fourth despreading means would be a fourth plurality of despread signals. The fourth combining means would combine the fourth plurality of despread signals as a fourth combined-despread signal. The selecting means selects one of the first combined-despread signal, the second combined-despread signal, the third combined-despread signal, or the fourth combined-despread signal, as the output-despread signal.

In a similar fashion, the fourth despreading means includes a fourth plurality of correlators, or a fourth plurality of matched filters, for despreading the fourth plurality of spread-spectrum signals for generating the fourth plurality of despread signals. Each correlator of the fourth plurality of correlators would despread with a chipping-sequence signal having a time delay different from each time delay of each chipping-sequence signal used, respectively, with other correlators of the fourth plurality of correlators. Also, the chipping-sequence signal would be different from the chipping-sequence signals used with each correlator of the third plurality of correlators, each chipping-sequence signal used with each correlator of the second plurality of correlators, and each chipping-sequence signal used with each correlator of the first plurality of correlators. Based on the disclosure herein, a person skilled in the art would readily know how to extend the concept to a fifth group of spread-spectrum signals, or more generally, to a plurality of groups of spread-spectrum signals.

Each of the matched filters may be realized using surface-acoustic-wave (SAW) devices, digital matched filters, or embodied in an application specific integrated circuit

(ASIC) chip or a digital signal processor (DSP) chip. Techniques for designing matched filters using these devices are well known in the art.

A multipath processor can single out individual paths from a group of rays. The weight for each weighting device is figured out by sets of correlators, and with a reference code it is possible to track the chipping-sequence signal in each ray. Alternatively, a method using a multipath processor may be used for tracking a spread-spectrum signal within a plurality of groups. The method comprises the steps of despreading the received signal r(t) received as the first plurality of spread-spectrum signals within a first group to generate a first plurality of despread signals. The first plurality of despread signals are then combined as a first combined-despread signal. The method would include despreading the received signal r(t) received as a second plurality of spread-spectrum signals within a second group to generate a second plurality of despread signals. The second plurality of despread signals would be combined as a second combined-despread signal. The method includes selecting either the first combined-despread signal or the second combined-despread signal, as an output-despread signal.

The step of despreading the first plurality of spread-spectrum signals may include the step of correlating or matched filtering the first plurality of spread-spectrum signals, using a first plurality of correlators or a first plurality of matched filters, respectively. The step of despreading the second plurality of spread-spectrum signals may include the step of correlating or matched filtering the second plurality of spread-spectrum signals using a second plurality of correlators or a second plurality of matched filters, respectively.

The method may further include despreading a third plurality of spread-spectrum signals within a third group to generate a third plurality of despread signals. The third plurality of despread signals would be combined as a third combined-despread signal. The selecting step would thereby include selecting one of the first combined-despread signal, the second combined-despread signal or the third combined-despread signal, as the output-despread signal. Similarly, the step of despreading the third plurality of spread-spectrum signals may include the step of correlating or matched filtering the third plurality of spread-spectrum signals using a third plurality of correlators or a third plurality of matched filters, respectively.

The step of despreading each of the first plurality of spread-spectrum signals would include the step of despreading with a chipping-sequence signal having a time delay different from each time delay of each chipping-sequence signal used to despread other spread-spectrum signals of the first plurality of spread-spectrum signals. Similarly, the step of despreading each of the second plurality of spread-spectrum signals would include the step of despreading with a chipping-sequence signal having a time delay different from each time delay of each chipping-sequence signal used to despread other spread-spectrum signals of the second plurality of spread-spectrum signals. Also, the step of despreading each of the second plurality of spread-spectrum signals would include the step of despreading with a chipping-sequence signal having a time delay different from each time delay of each chipping-sequence signal used to despread other spread-spectrum signals of the first plurality of spread-spectrum signals.

In the event the method includes the step of despreading a third plurality of spread-spectrum signals, the method would include the steps of despreading with a chipping-sequence signal having a time delay different for each time delay of each chipping-sequence signal used to despread other spread-spectrum signals of the third plurality of spread-spectrum signals. Also, the time delay would be different for each chipping-sequence signal used to despread spread-spectrum signals of the second plurality of spread-spectrum signals, and different from each time delay of each chipping-sequence signal used to despread spread-spectrum signals of the first plurality of spread-spectrum signals.

The method may be extended to a fourth, fifth or plurality of groups of spread-spectrum signals.

Variable Bandwidth Filter

The present invention also includes a variable-bandwidth spread-spectrum device for use with a spread-spectrum transmitter. The variable-bandwidth spread-spectrum device generates a spread-spectrum signal having a spread bandwidth. The term "spread bandwidth", as used herein, denotes the bandwidth of the transmitted spread-spectrum signal. The variable-bandwidth spread-spectrum device uses a chipping-sequence signal having a chipping rate which is less than the spread bandwidth. The term "chipping rate", as used herein, denotes the bandwidth of the chipping-sequence signal.

The variable-bandwidth spread-spectrum device includes first generating means, second generating means, spread-spectrum processing means, and filtering means. The spread-spectrum processing means is coupled to the first generating means. The second generating means is coupled between the spread-spectrum processing means and the filtering means.

The first generating means generates the chipping-sequence signal with the chipping rate. The spread-spectrum processing means processes a data signal with the chipping-sequence signal to generate a spread-data signal. The second generating means generates an impulse signal, in response to each chip of the spread-data signal. The filtering means filters the spectrum of each impulse signal with a bandpass equal to the spread bandwidth.

As illustratively shown in FIG. **16**, the first generating means may be embodied as a chipping-sequence generator **161**, the second generating means may be embodied as an impulse generator **165**, the spread-spectrum processing means may be embodied as an EXCLUSIVE-OR gate product device **164**, or other device known to those skilled in the art for mixing a data signal with a chipping-sequence signal, and the filtering means may be embodied as a filter **166**.

The product device **164** is coupled to the chipping-sequence generator **161**. The impulse generator **165** is coupled between the product device **164** and the filter **166**.

The chipping-sequence generator **161** generates the chipping-sequence signal with the chipping rate. The product device **164** processes the data signal with the chipping-sequence signal, thereby generating a spread-data signal as shown in FIG. **17**. The impulse generator **165** generates an impulse signal, as shown in FIG. **18**, in response to each chip in the spread-data signal shown in FIG. **17**. Each impulse signal of FIG. **18** has an impulse bandwidth. The term "impulse bandwidth", as used herein, denotes the bandwidth of the impulse signal. While theoretically an impulse signal has infinite bandwidth, practically, the impulse signal has a bandwidth which is greater than the spread bandwidth.

The filter **166** has a bandwidth adjusted to the spread bandwidth. Thus, the filter **166** filters a spectrum of each

impulse signal of the spread-data signal with the spread bandwidth. The filter **166** does this for each impulse signal.

The filter **166** preferably includes a variable-bandwidth filter. The variable-bandwidth filter may be used for varying or adjusting the spread bandwidth of the spectrum for each impulse signal. Accordingly, a spread-spectrum signal may be designed having the bandwidth of choice, based on the bandwidth of the variable-bandwidth filter. The bandwidth may be variable, or adjustable, as would be required for particular system requirements. As used in this patent, a variable bandwidth is one that is able to vary according to time conditions, background signals or interference, or other requirements in a particular system. An adjustable bandwidth would be similar to a variable bandwidth, but is used to refer to a bandwidth which may be adjusted to remain at a chosen setting.

The first generating means, as shown in FIG. **19**, may include a frequency-domain-chipping-sequence generator **161** and an inverse-Fourier-transform device **162**. The frequency-domain-chipping-sequence generator **161** may be used to generate a frequency-domain representation of a chipping-sequence signal. The inverse-Fourier-transform device **162** transforms the frequency-domain representation of the chipping-sequence signal to the chipping-sequence signal.

The first generating means may further include a memory **163** for storing the chipping-sequence signal.

The present invention also includes a variable-bandwidth spread-spectrum method for use with a transmitter. The method includes the steps of generating the chipping-sequence signal with the chipping rate, and spread-spectrum processing a data signal with the chipping-sequence signal to generate a spread-data signal. Each chip in the spread-spectrum signal is used to generate an impulse signal. Each impulse signal is filtered with the spread bandwidth to generate the desired bandwidth signal.

Thus, the variable-bandwidth-spread-spectrum device uses a lower chip rate, but provides a wider bandwidth signal. The power spectral density at the output of the filter **166** of the filtered-spread-data signal s(t) is proportional to the frequency response H(f) of the filter.

$$PSD_{s(t)}=k|H(f)|^2$$

Thus, the filter **166** controls the shape of the spectrum of the filtered-spread-data signal.

The processing gain (PG) is bandwidth W of the filtered-spread-data signal divided by chip rate R_b of the filtered-spread-data signal.

$$PG=W/R_b$$

The capacity N of the filtered-spread-data signal is

$$N \leqq \frac{PG}{E_b/N_o}+1$$

The capacity does not depend on chip rate, but instead on bandwidth. One can achieve an upper bound on the capacity if the chip rate is greater than the bandwidth. But, if the chip rate were lower, then one can save power consumption, i.e., use a lower clock rate of CMOS, which determines power consumption.

Adaptive Power Control System

The present invention assumes that a plurality of mobile stations operate in a cellular-communications network using spread-spectrum modulation. The cellular communications network has a plurality of geographical regions, with a multiplicity of cells within each geographical region. The size of the cells in a first geographical region may differ from the size of the cells in a second geographical region. In a first geographical region, such as an urban environment, the cellular architecture may have a large number of cells, each of small area, which place the corresponding base station close to each other. In a second geographical region, such as a rural environment, the cellular architecture may have a smaller number of cells, each of larger area. Further, the size of the cells may vary even within a specified geographic region.

A mobile station, while in the urban environment of the first geographical region, may be required to transmit at a lower power level than while in the rural environment of the second geographical region. This requirement might be due to a decreased range of the mobile station from the base station. Within a particular cell, a mobile station near the base station of the cell may be required to transmit with a power level less than that required when the mobile station is near an outer perimeter of the cell. This adjustment in power level is necessary to ensure a constant power level is received at the base station from each mobile station.

Adaptive power control works by measuring the received signal to noise ratio (SNR) for each user and causing the user transmitted power to vary in a manner to cause all users' SNR's to be equal to a common value which will be adequate for reliable communication if the total number of users and interference is less than system capacity. While this assumes that all users are obtaining the same service, e.g., 32 kbs voice data, it is a feature of the system described that different service options are supported for requesting users. This is done by adjusting the setpoint for each user independently.

There are two issues that arise when addressing the base operation of an adaptive power control system. The first is the common value obtained for SNR versus the load and its cost to the transmitters in terms of transmitted power, and the second is the stability of the system. Stability means that a perturbation of the system from its quiescent state causes a reaction of the system to restore the quiescent condition. It is highly desirable that there exist only one quiescent point because otherwise "chatter" or oscillation may occur. Stability must be addressed with any control system but, in the present case, the situation is somewhat complicated by the fact that the users affect one another, and thereby cause the control variables, the transmitted power and resulting SNR's, to be dynamically coupled. The coupling is apparent when one realizes that all signals are processed by a common AGC function which does not discriminate individual user signals from each other or from other sources.

The power control scheme of the present invention is a closed loop scheme. The system measures the correlator output power for each user and compares the measured value with a target value or setpoint. This measured power includes both the desired signal component and unwanted power or noise.

The AGC maintains the total power into each correlator at a preset level. This level does not vary as a function of APC action; that is, this role of the AGC is independent of APC. Furthermore, an increase in received power from any user or subset of users will be "attacked" by the AGC. This is possible because the AGC time constant is smaller than the APC time constant, i.e., the AGC is faster than the APC. Since the total power available out of the AGC is fixed, an

increase in the portion due to one user comes at the expense of all other users. While this may work against the apparent stability of the system, the AGC sensor, which measures the AGC control signal and thereby measures the total received power, causes the system to seek a quiescent state corresponding to the minimum received power per user. It is desired that the transmitted power be minimized because this will minimize intercell interference and conserve battery power. Excess transmitter power will be dissipated within the AGC as long as all users transmit excessive power.

The implementation shown in the figures is to be considered representative. In particular, the method of controlling the remote transmitter power via attenuators and variable gain amplifiers is perhaps redundant. Either or both of these means may be employed, depending upon the (dynamic) range of control required. Also, control may be caused at either IF or RF frequencies.

For discussion purposes, a mobile station within a particular cell transmits a first spread-spectrum signal, and the base station transmits a second spread-spectrum signal.

In the exemplary arrangement shown in FIG. **20**, a block diagram of a base station as part of a system for adaptive-power control of a spread-spectrum transmitter is provided.

FIG. **20** illustrates the base station adaptive power control system with automatic gain control (AGC) means, power means, comparator means, transmitter means, and an antenna. The AGC means is shown as an automatic-gain-control (AGC) amplifier **228**, correlator means is shown as despreader **231**, and power means is shown as power measurement device **233**. The comparator means is shown as comparator **239**, the transmitter means is shown as power amplifier **237** coupled to the antenna **226**. Also illustrated is a delta modulator **235** coupled between comparator **239** and power amplifier **237**.

The AGC amplifier **228** is coupled to the despreader **231**. The power measurement device **233** is coupled to the despreader **231**. The comparator **239** is coupled to the output of the power measurement device **233** and to the AGC amplifier **228**. The multiplexer **234** is coupled between the comparator **239** and the power amplifier **237**. The delta modulator **235** is coupled between the power amplifier **237** and the multiplexer **234**. The power amplifier **237** is coupled to the antenna **226**.

A threshold level is used by the comparator **239** as a comparison for the received-power level measured by the power measurement device **233**.

For each received signal, the AGC amplifier **228** generates an AGC-output signal and an AGC-control signal. The AGC-output signal is despread to obtain the signal of a first user using despreader **231**. The despread-AGC-output signal from the despreader **231** is combined with the AGC-control signal from the AGC amplifier **228**, by the combiner **241**. The AGC-control signal from the AGC amplifier **228** may be offset by offset level S_1 using combiner **242**, and weighted by weighting device **243**. The weighting device **243** may be an amplifier or attenuator.

The received-power level from power device **233** may be offset by offset level S_2 using combiner **244**, and weighted by weighting device **245**. The weighting device **245** may be an amplifier or attenuator. The combiner **241** combines the AGC-control signal with the received-level signal, for generating adjusted-received-power level. The comparator **239** generates a comparison signal by comparing the adjusted-received-power level to the threshold level. The comparison signal may be an analog or digital data signal. The comparison signal indicates whether the mobile station is to increase or decrease its power level. If the adjusted-received-power level exceeds the threshold, for example, then the comparison signal sends a message to the mobile station to decrease its transmitter power. If the adjusted-received-power level were below the threshold, then the comparison signal sends a message to the mobile station to increase its transmitter power. The comparison signal is converted to a power-command signal by the delta modulator **235**.

The power-command signal may be transmitted with or separate from the second spread-spectrum signal. For example, a spread-spectrum signal using a first chip sequence may be considered a first spread-spectrum channel, and a spread-spectrum signal using a second chip sequence may be considered a second spread-spectrum channel. The power-command signal may be transmitted in the same spread-spectrum channel, i.e., the first spread-spectrum channel, as the second spread-spectrum signal, in which case the power-command signal is transmitted at a different time interval from when the second spread-spectrum signal is transmitted. This format allows the mobile station to acquire synchronization with the first sequence, using the second spread-spectrum signal. The power-command signal may also be transmitted in a second spread-spectrum channel which is different from the second spread-spectrum signal. In this case, the second spread-spectrum signal having the power-command signal would be acquired by the second chipping-sequence generator and second product device. The power-command signal may be time division multiplexed or frequency division multiplexed with the second spread-spectrum signal.

The base-correlator means is depicted in FIG. **20** as first despreader **231**. The system, by way of this example, may have the base-correlator means embodied as a product device, a chip-sequence generator, and a bandpass filter. Alternatively, the base-correlator means may be realized as a matched filter such as a surface-acoustic-wave device, or as a digital matched filter embodied in a digital signal processor. In general, the base-correlator means uses or is matched to the chip sequence of the spread-spectrum signal being received. Correlators and matched filters for despreading a spread-spectrum signal are well known in the art.

Typically, the AGC circuit **228** is coupled to a low noise amplifier **227**, through an isolator **225** to the antenna **226**. In FIG. **20** a plurality of despreaders, despreader **229** through despreader **231**, are shown for despreading a plurality of spread-spectrum channels which may be received from a plurality of mobile stations. Similarly, the output of each despreader **229** through despreader **231** is coupled to a plurality of demodulators, illustrated as demodulator **230** through demodulator **232**, respectively, for demodulating data from the despread AGC-output signal. Accordingly, a plurality of data outputs are available at the base station.

For a particular spread-spectrum channel, the first despreader **231** is shown coupled to power device **233** and multiplexer **234**. The power device **233** typically is a power-measurement circuit which processes the despread AGC-output signal as a received-power level. The power device **233** might include an analog-to-digital converter circuit for outputting a digital received-power level. The comparator means, embodied as comparator circuit **239**, compares the processed received-power level to a threshold. The multiplexer **234** is coupled to the output of the power device **233** through the comparator circuit **239**. The multiplexer **234** may insert appropriate framing bits, as required.

The transmitter means may be embodied as a quadrature phase shift keying (QPSK) modulator or a delta modulator

235 coupled to a power amplifier 237. In FIG. 20, the input to the delta modulator 235 typically would have the comparison signal from the comparator 239 multiplexed with data from the k^{th} channel. The delta modulator 235 converts the comparison signal to a power-command signal. A plurality of spread spectrum channels would have their data and appropriate power-command signals combined by combiner 236 and amplified by power amplifier 237. The output of the power amplifier 237 is coupled through the isolator 125 to the antenna 226.

The power command signal is transmitted periodically. The period T might be chosen to be 250 microseconds in order to ensure a low root mean square error as well as a low peak error between the instantaneous received signal and the constant desired signal.

A mobile station is illustratively shown in FIG. 21. The mobile-despreading means is illustrated as despreader 334 and variable-gain means is illustrated as a variable-gain device 341. The variable-gain device 341 is coupled between the transmitter 342 and through isolator 336 to antenna 335. The despreader 334 is coupled to the isolator 336 and to demultiplexer 339. The output of the despreader 334 is also coupled to a demodulator 340. The despreader 334 may be embodied as an appropriate correlator, or matched filter, for despreading the k^{th} channel. Additional circuitry may be used, such as radio frequency (RF) amplifiers and filters, or inter-mediate frequency (IF) amplifiers and filters, as is well known in the art.

A received second spread-spectrum signal at antenna 335 passes through isolator 336 to despreader 334. The despreader 334 is matched to the chip sequence of the desired spread-spectrum channel. The output of the despreader 334 passes through the demodulator 340 for demodulating the data from the desired spread-spectrum channel. Additionally, the demultiplexer 339 demultiplexes the power-command signal from the despread signal outputted from despreader 334. The power-command signal drives the variable-gain device 341.

A decision device 345 and accumulator 346 may be coupled between the demultiplexer 339 and the variable gain device 341. A step-size-algorithm device 344 is coupled to the output of the decision device 345 and to the accumulator 346.

The step-size-algorithm device 344 stores an algorithm for adjusting the power level of the variable gain device 341. A nonlinear algorithm that might be used is shown in FIG. 22. FIG. 23 compares a nonlinear algorithm with a linear step size algorithm.

The power-command signal from the demultiplexer 339 causes the decision device 345 to increase or decrease the power level of the variable gain device 341, based on the threshold of the step size algorithm shown in FIG. 23. The accumulator tracks previous power levels as a means for assessing the necessary adjustments in the step size of the power level pursuant to the algorithm as shown in FIG. 23.

The variable-gain device 341 may be embodied as a variable-gain amplifier, a variable-gain attenuator, or any device which performs the same function as the variable-gain device 341 as described herein. The variable-gain device 341 increases or decreases the power level of the remote station transmitter, based on the power-command signal.

As illustratively shown in FIG. 20, a block diagram of a power measurement circuit includes interference rejection for use with the base station. As shown in FIG. 20, the AGC amplifier 228 is connected to the despreader 231, and the

output of the despreader 231 is connected to the power measurement circuit 233. Additionally, the AGC amplifier 228 is connected to the combiner 236 through the comparator 239.

A received signal includes a first spread-spectrum signal with power P_C and the other input signals which are considered to be interfering signals with power P_I at the input to the AGC amplifier 228 of FIG. 20. The interfering signal may come from one or more nondesirable signals, noise, multipath signals, and any other source which would serve as an interfering signal to the first spread-spectrum signal. The received signal is normalized by the AGC amplifier 228. Thus, by way of example, the AGC amplifier 228 can have the power output, $P_C+P_I=1$. The normalized received signal is despread by the despreader 231 to receive a particular mobile user's signal. The chipping-sequence generator of despreader 231 generates a chip-sequence signal using the same chip sequence as used by the first spread-spectrum signal. Alternatively, the matched filter, if used, of despreader 231 may have an impulse response matched to the same chip sequence as used by the first spread-spectrum signal. The output of the despreader 231 is the normalized power of the first spread-spectrum signal plus the normalized power of the interfering signal divided by the processing gain, PG, of the spread-spectrum system. The power measurement circuit 233 generates a received-power level of the first spread-spectrum signal. The comparator 239 processes the despread-received signal with the AGC-control signal and outputs the power-control signal of the first spread-spectrum signal. The power level of the interfering signal is reduced by the processing gain, PG.

The comparator 239 processes the AGC-control signal with the despread, normalized received signal by multiplying the two signals together, or by logarithmically processing the AGC-control signal with the despread-received signal. In the latter case, the logarithm is taken of the power of the received signal, P_C+P_I, and the logarithm is taken of the despread, normalized received signal. The two logarithms are added together to produce the received-power level.

For the present invention to work effectively, the despread signal must be kept nearly constant, independent of variations in the other signals or of obstructions. A preferred implementation to accomplish this end is shown in the circuitry of FIG. 20. FIG. 20 depicts a means for determining at the base station the power of the first spread-spectrum signal when the received signal includes multiple signals and noise. If the circuitry of FIG. 20 were not used, then it is possible that the interfering signal, which may include noise, multipath signals, and other undesirable signals, may raise the power level measured at the input to the receiver of the base station, thereby suppressing the first spread spectrum signal. The undesirable power level measured may cause the remote station to transmit more power than required, increasing the amount of power received at the base station.

As noted earlier, the APC system is a closed loop system. The APC loop operates by generating commands to increase or decrease the transmitter power at the update rate. This is actually quantization process that is done to limit the amount of information that must be fed back to the remote transmitter. The amount of increase or decrease may be fixed in advance or it may adapt in response to the characteristics of the channel as measured locally in the remote terminal, the terminal being controlled. In particular, the remote terminal may examine the sequence of commands received by it. A long sequence of increase commands, for example, implies that the step size may be increased. A typical scheme

increases the step size by a fixed amount or a fixed percentage whenever two successive bits are the same. For example, the step size may be increased by 50% if two bits in a row are the same and decreased by 50% if they differ. This is a fairly gross change in the step size, and is intended to be adaptive to local, or immediate in time, variations in the required transmitted power. This process results in a large variation of the step size with time.

An adaptive step size algorithm may also be considered in a different context. Specifically, the step size may be considered to be nearly constant or not responding to localized variations in demanded transmitted power, but the value may be automatically adjusted based on the global characteristics of the channel induced control action. Thus, in a nearly static environment one should use a small constant step size while in a mobile environment the step size should be larger.

Adjustment of the power level of the remote station transmitter may be effected either linearly or nonlinearly. The following algorithm will cause the step size to settle at a nearly optimum constant value. The receiver examines successive APC bits and increases the step size by the factor (1+x) if they agree and decreases the step size by the factor (1+x) if they disagree. Here the parameter x is small (x=0.01, for example.) While this procedure will not allow local adaptation (because x is small), it will result in an adaptation to global conditions. Specifically, if the transmitted APC bit stream exhibits a tendency toward successive bits in agreement (i.e., runs of 1's or 0's are evident) it implies that the system is not following the changes in channel conditions (i.e., the system is slow rate limited) and the step size should be increased. On the other hand, if successive bits tend to be opposite, the system is "hunting" for a value between two values that are excessively far apart. The statistics one expects to observe as optimal are inter-mediate to these extremes. That is, the APC bit stream should appear equally likely to contain the patterns (0,0), (0,1), (1,0), and (1,1) in any pair of successive bits. The above algorithm drives the system behavior toward this.

The above algorithm (global adaptation) works particularly well when the system employs a high update rate relative to the dynamics of the channel.

As illustrated in FIG. 23, to increase the power level using linear adjustment, for example, the transmitter power is increased in regular increments of one volt, or other unit as instructed by the base station, until the power level received at the base station is sufficiently strong. Linear adjustment may be time consuming if the power adjustment necessary were substantial.

As shown in FIG. 22, to increase the power using nonlinear adjustment, the transmitter voltage may be increased, by way of example, geometrically until the transmitted power is in excess of the desired level. Transmitter power may be then reduced geometrically until transmitted power is below the desired level. A preferred approach is to increase the step size voltage by a factor of 1.5 and to decrease the step size by a factor of 0.5. Other nonlinear algorithms may be used. As shown in FIG. 23, this process is repeated, with diminishing margins of error in both excess and insufficiency of desired power, until the desired signal level has been obtained. Nonlinear adjustment provides a significantly faster rise and fall time than does linear adjustment, and may be preferable if power must be adjusted significantly.

The system determines the error state (APC bit) every T sections, 1/T being the update rate of the control. The update rate may vary from 100 Hz, which is low, to 100 kHz, which is quite high. The opportunity to measure the error state of the system arises with each reception of a new symbol. Thus, the update rate may be equal to the symbol rate. If such an update rate is not supported, it is beneficial to make use of the available error measurements by combining them (or averaging them) between updates. This minimizes the chance of causing a power adjustment in the wrong direction which can occur because of noise in the error signals themselves.

The choice of update rate depends on factors other than APC operation, namely, the amount of capacity and method of allocating capacity to the transport of the APC bits over the channel. In general, a faster update will produce superior performance, even if the increased update rate is obtained by permitting the APC bits to be received in error occasionally. Elaborating, a 1 kHz update rate with no channel induced errors will perform less effectively than a 100 kHz update rate at a 25% rate of errors. This is because of the self correcting behavior of the control loop. A faster update rate eliminates the latency of control which is a key performance limiting phenomenon.

A spread spectrum base station receives all incoming signals simultaneously. Thus, if a signal were received at a higher power level than the others, then that signal's receiver has a higher signal-to-noise ratio and therefore a lower bit error rate. The base station ensures that each mobile station transmits at the correct power level by telling the remote, every 500 microseconds, whether to increase or to decrease the mobile station's power.

FIG. 24 shows a typical fading signal which is received at the base station along with ten other independently fading signals and thermal noise having the same power as one of the signals. Note that the fade duration is about 5 milliseconds which corresponds to vehicular speed exceeding 60 miles per hour. FIGS. 25–26 illustrate the results obtained when using a particular adaptive power control algorithm. In this case, whenever the received signal changes power, the base station informs the remote and the remote varies its power by ±1 dB. FIG. 25 shows the adaptive power control signal at the remote station. FIG. 26 shows the received power at the base station. Note that the adaptive power control track the deep fades and as a result 9 dB fades resulted. This reduced power level resulted in a bit error rate of 1.4×10^{-2}.

For the same fade of FIG. 24, assume a different adaptive power control algorithm is employed as shown in FIGS. 27–28. In this case the control voltage results in the remote unit changing its power by a factor of 1.5 in the same direction, or by a factor of 0.5 in the opposite direction. In this particular implementation the minimum step size was 0.25 dB and the maximum step size was 4 dB. Note that the error is usually limited to ±2 dB with occasional decreases in power by 5 dB to 6 dB resulting in a BER$\approx8\times10^{-4}$, a significant improvement compared to the previous algorithm. The use of interleaving and forward error correcting codes usually can correct any errors resulting from the rarely observed power dips.

In operation, a mobile station in a cell may transmit the first spread-spectrum signal on a continuous basis or on a repetitive periodic basis. The base station within the cell receives the first spread-spectrum signal. The received first spread-spectrum signal is acquired and despread with the chip-sequence signal from chip-sequence generator and product device. The despread first spread-spectrum signal is filtered through bandpass filter. The base station detects the

despread first spread-spectrum signal using envelope detector, and measures or determines the received-power level of the first spread-spectrum signal. The base station generates the power-command signal from the received-power level.

The present invention also includes a method for automatic-power control of a spread-spectrum transmitter for a mobile station operating in a cellular-communications network using spread-spectrum modulation, with the mobile station transmitting a first spread-spectrum signal. In use, the method includes the step of receiving a received signal, generating an AGC-output signal, despreading the AGC-output signal, processing the despread AGC-output signal to generate a received-power level, generating a power-command signal, transmitting the power-command signal as a second spread-spectrum signal, despreading the power-command signal from the second spread-spectrum signal as a power-adjust signal, and adjusting a power level of the first spread-spectrum signal.

The received signal includes the first spread-spectrum signal and an interfering signal and is received at the base station. The AGC-output signal is generated at the base station and despread as a despread AGC-output signal. The despread AGC-output signal is processed at the base station to generate a received-power level.

The received-power level is compared to a threshold, with the comparison used to generate a power-command signal. If the received-power level were greater than the threshold, the power-command signal would command the mobile station to reduce transmitter power. If the received-power level were less than the threshold, the power-command signal would command the mobile station to increase transmitter power.

The power-command signal is transmitted from the base station to the mobile station as a second spread-spectrum signal. Responsive to receiving the second spread-spectrum signal, the mobile station despreads the power-command signal as a power-adjust signal. Depending on whether the power-command signal commanded the mobile station to increase or decrease transmitter power, the mobile station, responsive to the power adjust signal, increases or decreases the transmitter-power level of the first spread-spectrum signal, respectively.

The method may additionally include generating from a received signal an AGC-output signal, and despreading the AGC-output signal. The received signal includes the first spread-spectrum signal and an interfering signal. The received signal is processed with the despread AGC-output signal to generate a received-power level. The method then generates a comparison signal by comparing the received-power level to the threshold level. While transmitting a second spread-spectrum signal, the method adjusts a transmitter-power level of the first spread-spectrum signal from the transmitter using the power-adjust signal.

It will be apparent to those skilled in the art that various modifications can be made to the spread-spectrum system and method of the instant invention without departing from the scope or spirit of the invention, and it is intended that the present invention cover modifications and variations of the spread-spectrum system and method provided they come within the scope of the appended claims and their equivalents.

I claim:

1. A system for adaptive-power control of a spread-spectrum transmitter of a mobile station operating in a cellular-communications network using spread-spectrum modulation, comprising:

a mobile station having a mobile transmitter coupled to a mobile antenna for transmitting a first spread-spectrum signal using radio waves;

a base station having

an automatic-gain-control (AGC) circuit, responsive to a received signal, for generating an AGC-output signal, with the received signal including the first spread-spectrum signal and an interfering signal;

a base correlator coupled to said AGC circuit for despreading the AGC-output signal;

a power-measurement circuit coupled to said base-correlator, for processing the despread AGC-output signal as a received-power level;

a comparator coupled to said power-measurement circuit for generating a comparison signal by comparing the received-power level to a threshold level;

a power-command circuit coupled to said comparator and responsive to the comparison signal for generating a power-command signal;

an antenna;

a transmitter coupled to said antenna and to said power-command circuit for transmitting the power-command signal as a second spread-spectrum signal; and

said mobile station further including

a mobile correlator coupled to said mobile antenna for despreading the power-command signal from the second spread-spectrum signal as a power-adjust signal;

a decision device coupled to said mobile correlator for responding to the power-adjust signal;

an accumulator coupled to said decision device;

a step-size algorithm device coupled to said decision device and to said accumulator for storing an algorithm for adjusting a power level; and

a first variable-gain device coupled to said accumulator, responsive to the power-adjust signal, for adjusting a transmitter-power level of the first spread-spectrum signal transmitted from said mobile-transmitter.

2. The system as set forth in claim 1 with said power-measurement circuit coupled to said AGC circuit and to said base-correlator, responsive to processing the received signal with the despread AGC-output signal, for generating the received-power level.

3. The system as set forth in claim 1 or 2 with said first variable-gain device adjusting the transmitter-power level using nonlinear steps in power level.

4. A system for adaptive-power control of a spread-spectrum transmitter of a mobile station operating in a cellular-communications network using spread-spectrum modulation, with the mobile station transmitting a first spread-spectrum signal, said system comprising:

a base station having,

automatic gain control (AGC) means, responsive to a received signal, with the received signal including the first spread-spectrum signal and an interfering signal, for generating an AGC-output signal and an AGC-control signal;

base-correlator means for despreading the AGC-output signal as a despread AGC-output signal;

power means for processing the despread AGC-output signal as a received-power level;

comparator means for comparing the received-power level to a threshold level to generate a comparison signal;

modulator means for converting the comparison signal to a power command signal; and

transmitter means for transmitting the power-command signal as a second spread-spectrum signal;

a mobile station having,

despreader means for despreading the power-command signal from the second spread-spectrum signal as a power-adjust signal;

decision means, responsive to the power-adjust signal, for increasing or decreasing a power level; and

variable-gain means, responsive to said decision means, for adjusting a transmitter-power level of the first spread-spectrum signal.

5. The system as set forth in claim 4 with said power means responsive to processing the received signal with the despread AGC-output signal, for generating the received-power level.

6. The system as set forth in claim 4 with said variable-gain means adjusting the transmitter-power level using nonlinear steps in power level.

7. The system as set forth in claim 5 with said variable-gain means adjusting the transmitter-power level using nonlinear steps in power level.

8. The system as set forth in claim 4, 5, 6 or 7 wherein said AGC means includes an automatic-gain-control circuit.

9. The system as set forth in claim 4, 5, 6 or 7 wherein said variable-gain means includes a variable-gain attenuator for adjusting the transmitter-power level.

10. The system as set forth in claim 4, 5, 6 or 7 wherein said variable-gain means includes a variable-gain amplifier for adjusting the transmitter-power level.

11. A method for adaptive-power control, from a base station, of a spread-spectrum transmitter of a mobile station operating in a cellular-communications network using spread-spectrum modulation, with the mobile station transmitting a first spread-spectrum signal, said method comprising the steps of:

generating, at said base station, from a received signal, with the received signal including the first spread-spectrum signal and an interfering signal, an AGC-output signal;

despreading, at said base station, the AGC-output signal as a despread AGC-output signal;

processing, at said base station, the despread AGC-output signal to generate a received-power level;

generating, at said base station, a comparison signal from comparing the received-power level to a threshold generating, at said base station, a power command signal responsive to said comparison signal;

transmitting, from said base station, the power-command signal as a second spread-spectrum signal;

despreading, at said mobile station, the power-command signal from the second spread-spectrum signal as a power-adjust signal; and

adjusting, at said mobile station, responsive to the power-adjust signal, a transmitter-power level of the first spread-spectrum signal.

12. The method as set forth in claim 11 wherein the step of adjusting includes the step of adjusting the transmitter-power level using nonlinear steps in power level.

13. A system for adaptive-power control of a spread-spectrum transmitter of a mobile station operating in a cellular-communications network using spread-spectrum modulation, comprising:

a mobile station having a mobile transmitter coupled to a mobile antenna for transmitting a first spread-spectrum signal using radio waves;

a base station having

an automatic-gain-control (AGC) circuit, responsive to a received signal, for generating an AGC-output signal and an AGC-control signal, with the received signal including the first spread-spectrum signal and an interfering signal;

a first combiner, coupled to said AGC circuit, for offsetting the AGC-control signal;

a first weighting device, coupled to said first combiner, for weighting the AGC-control signal;

a base correlator coupled to said AGC circuit for despreading the AGC-output signal;

a power-measurement circuit coupled to said base-correlator, for processing the despread AGC-output signal as a received-power level;

a demodulator, coupled to said power-measurement circuit, for demodulating data from the despread AGC-output signal;

a second combiner, coupled to said power-measurement circuit, for offsetting the received-power level;

a second weighting device, coupled to said second combiner, for weighting the received-power level;

a third combiner, coupled to said second weighting device and to said first weighting device, for combining the received-power level and the AGC-control signal as an adjusted-received-power level;

a comparator coupled to said power-measurement circuit through said third combiner for generating a comparison signal by comparing the adjusted-received-power level to a threshold level;

a power-command circuit coupled to said comparator and responsive to the comparison signal for generating a power-command signal;

an antenna;

a transmitter coupled to said antenna and to said power-command circuit for transmitting the power-command signal as a second spread-spectrum signal; and

said mobile station further including

a despreader coupled to said mobile antenna, for despreading the power-command signal from the second spread-spectrum signal as a power-adjust signal;

a demultiplexer, coupled to said despreader, for demultiplexing the power-adjust signal from despread data;

a decision device, coupled to said demultiplexer, for responding to the power-adjust signal;

an accumulator, coupled to said decision device, for tracking previous power levels;

a step-size algorithm device, coupled to said decision device and to said accumulator, for storing an algorithm for adjusting a power level; and

a variable-gain device, coupled to said accumulator, responsive to the power-adjust signal, for adjusting a transmitter-power level of the first spread-spectrum signal transmitted from said mobile-transmitter.

14. The system as set forth in claim 13 further comprising:

a plurality of base correlators coupled to said AGC circuit for despreading a plurality of channels, respectively, as a plurality of despread data;

a plurality of power-measurement circuits coupled to said plurality of base correlators, respectively;

a plurality of demodulators coupled to said plurality of power-measurement circuits, respectively; and

a fourth combiner, coupled to said power-command circuit, for combining the plurality of despread data received from the plurality of channels.

15. The system as set forth in claim 13 with said variable-gain device, responsive to the algorithm stored in said step-size algorithm device, adjusting the transmitter-power level using nonlinear steps in power level.

16. A system for adaptive-power control of a spread-spectrum transmitter of a mobile station operating in a cellular-communications network using spread-spectrum modulation, with the mobile station transmitting a first spread-spectrum signal, said system comprising:

a base station having,

automatic gain control (AGC) means, responsive to a received signal, with the received signal including the first spread-spectrum signal and an interfering signal, for generating an AGC-output signal and an AGC-control signal;

first combining means for offsetting the AGC-control signal;

first weighting means for weighting the offset AGC-control signal;

base-correlator means for despreading the AGC-output signal as a despread AGC-output signal;

power measurement means for processing the despread AGC-output signal as a received-power level;

demodulating means for demodulating data from the despread AGC-output signal;

second combining means for offsetting the received-power level;

second weighting means for weighting the offset received-power level;

third combining means for combining the weighted-offset-received-power level and the weighted-offset AGC-control signal as an adjusted-received-power level;

comparator means for comparing the adjusted-received-power level to a threshold level and for outputting a power-control signal;

delta modulating means for converting the power-control signal to a power-command signal; and

transmitter means for transmitting the power-command signal as a second spread-spectrum signal;

a mobile station having,

despreading means for despreading the power-command signal from the second spread-spectrum signal as a power-adjust signal;

decision means, responsive to the power-adjust signal, for increasing or decreasing a power level;

accumulating means for tracking previous power levels;

algorithm storing means for storing an algorithm to adjust a power level; and

variable-gain means, responsive to said decision means and to said algorithm storing means, for adjusting a transmitter-power level of the first spread-spectrum signal.

17. The system as set forth in claim 16 further comprising:

a plurality of base correlator means for despreading a plurality of channels, respectively, as a plurality of AGC-output signals;

a plurality of power measurement means for processing the plurality of despread-AGC-output signals, respectively;

a plurality of demodulating means for demodulating the plurality of processed-despread-AGC-output signals, respectively; and

fourth combining means for combining the plurality of demodulated-processed-despread-AGC-output signals prior to transmission as a second spread-spectrum signal.

18. The system as set forth in claim 16 or 17 with said variable-gain means adjusting the transmitter-power level using nonlinear steps in power level.

19. The system as set forth in claim 16 or 17 with said variable-gain means adjusting the transmitter-power level using linear steps in power level.

20. The system as set forth in claim 16, 18 or 19 wherein said AGC means includes an automatic-gain-control circuit.

21. The system as set forth in claim 16, 18 or 19 wherein said variable-gain means includes a variable-gain attenuator for adjusting the transmitter-power level.

22. The system as set forth in claim 16, 18 or 19 wherein said variable-gain means includes a variable-gain amplifier for adjusting the transmitter-power level.

23. A method for adaptive-power control, from a base station, of a spread-spectrum transmitter of a mobile station operating in a cellular-communications network using spread-spectrum modulation, with the mobile station transmitting a first spread-spectrum signal, said method comprising the steps of:

generating, at said base station, from a received signal, with the received signal including the first spread-spectrum signal and an interfering signal, an AGC-output signal and an AGC-control signal;

despreading, at said base station, the AGC-output signal as a despread-AGC-output signal;

offsetting the AGC-control signal;

weighting the offset-AGC-control signal;

processing, at said base station, the despread AGC-output signal to generate a received-power level;

offsetting the received-power level;

weighting the offset-received-power level;

combining the weighted-offset-received-power level and the weighted-offset-AGC-control signal as an adjusted-received power control signal;

comparing the adjusted-received-power control signal to a threshold;

generating, at said base station, a power-command signal from the comparison;

transmitting, from said base station, the power-command signal as a second spread-spectrum signal;

despreading, at said mobile station, the power-command signal from the second spread-spectrum signal as a power-adjust signal;

tracking previous power levels; and

adjusting, at said mobile station, responsive to the power-adjust signal and tracked previous power levels, a transmitter-power level of the first spread-spectrum signal.

24. The method as set forth in claim 23 wherein the step of adjusting includes the step of adjusting the transmitter-power level using nonlinear steps in power level.

* * * * *

US006181949B1

(12) **United States Patent**
Ozluturk et al.

(10) **Patent No.: US 6,181,949 B1**
(45) **Date of Patent: Jan. 30, 2001**

(54) **METHOD OF CONTROLLING INITIAL POWER RAMP-UP IN CDMA SYSTEMS BY USING SHORT CODES**

(75) Inventors: **Fatih M. Ozluturk**, Port Washington; **Gary R. Lomp**, Cenerport, both of NY (US)

(73) Assignee: **InterDigital Technology Corporation**, Wilmington, DE (US)

(*) Notice: Under 35 U.S.C. 154(b), the term of this patent shall be extended for 0 days.

(21) Appl. No.: **09/003,104**

(22) Filed: **Jan. 6, 1998**

(51) **Int. Cl.**[7] **H04B 7/00**
(52) **U.S. Cl.** **455/522**; 455/69; 375/200
(58) **Field of Search** 455/510, 522, 455/67.1, 69, 437, 452, 67.4; 375/200

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* cited by examiner

Primary Examiner—Daniel S. Hunter
Assistant Examiner—Darnell R. Armstrong
(74) *Attorney, Agent, or Firm*—Volpe & Koenig, P.C.

(57) **ABSTRACT**

A system and method of controlling transmission power during the establishment of a channel in a CDMA communication system utilize the transmission of a short code from a subscriber unit to a base station during initial power ramp-up. The short code is a sequence for detection by the base station which has a much shorter period than a conventional spreading code. The ramp-up starts from a power level that is guaranteed to be lower than the required power level for detection by the base station. The subscriber unit quickly increases transmission power while repeatedly transmitting the short code until the signal is detected by the base station. Once the base station detects the short code, it sends an indication to the subscriber unit to cease increasing transmission power. The use of short codes limits power overshoot and interference to other subscriber stations and permits the base station to quickly synchronize to the spreading code used by the subscriber unit.

10 Claims, 11 Drawing Sheets

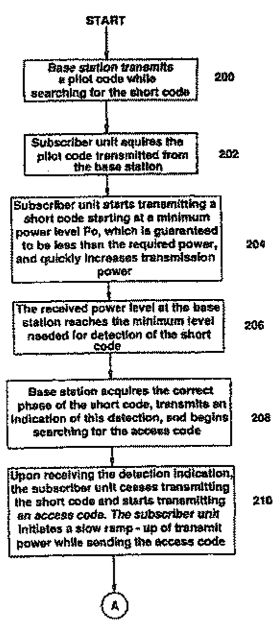


FIG.1

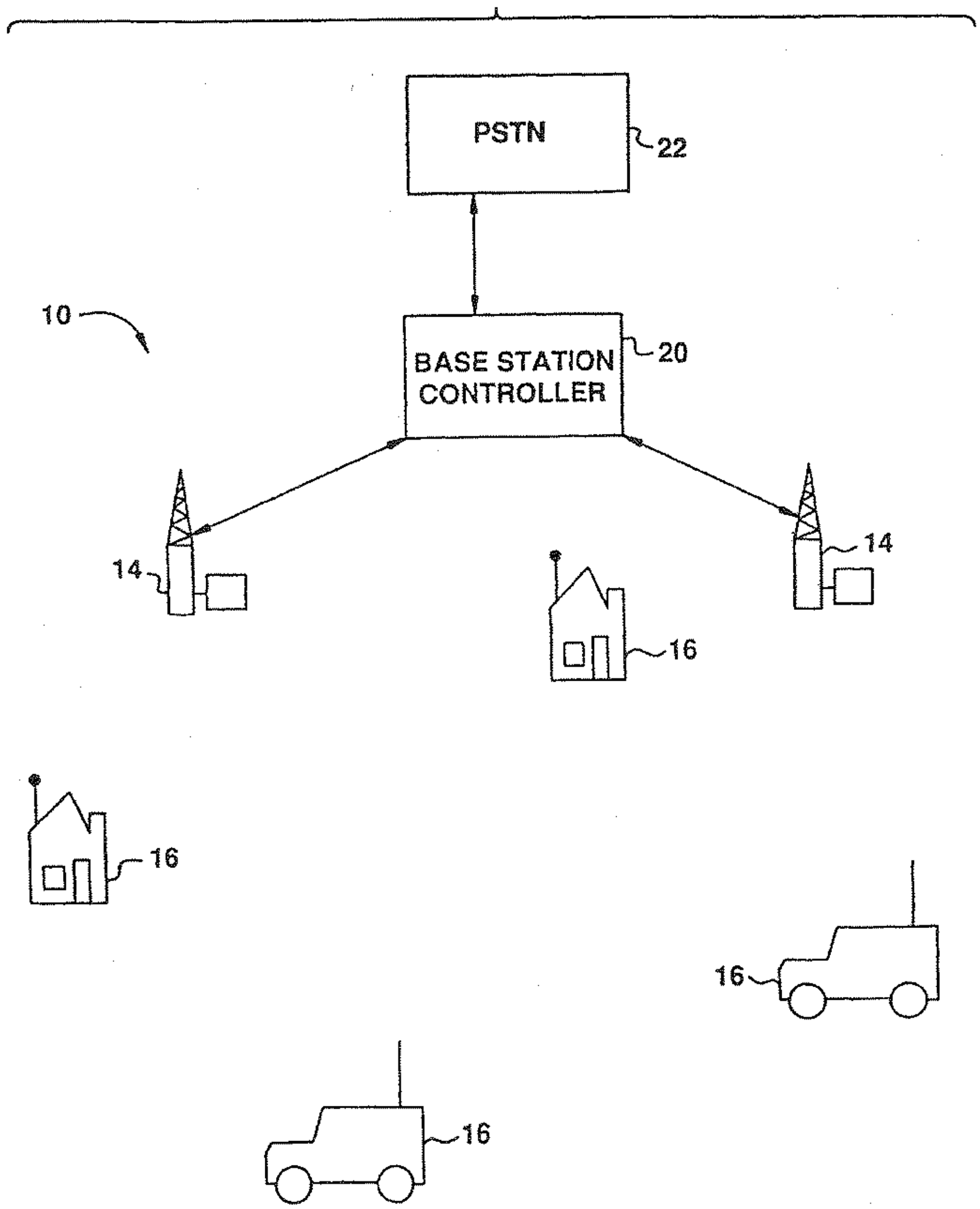


FIG.2

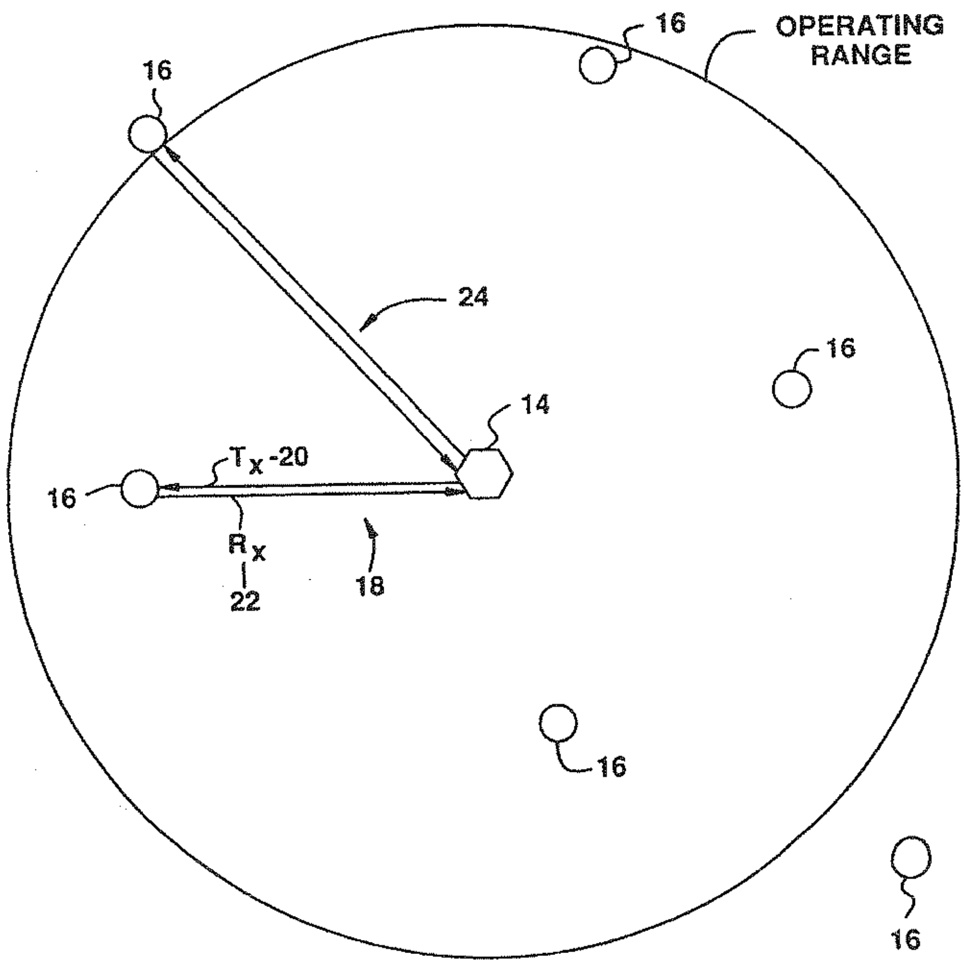


FIG.3

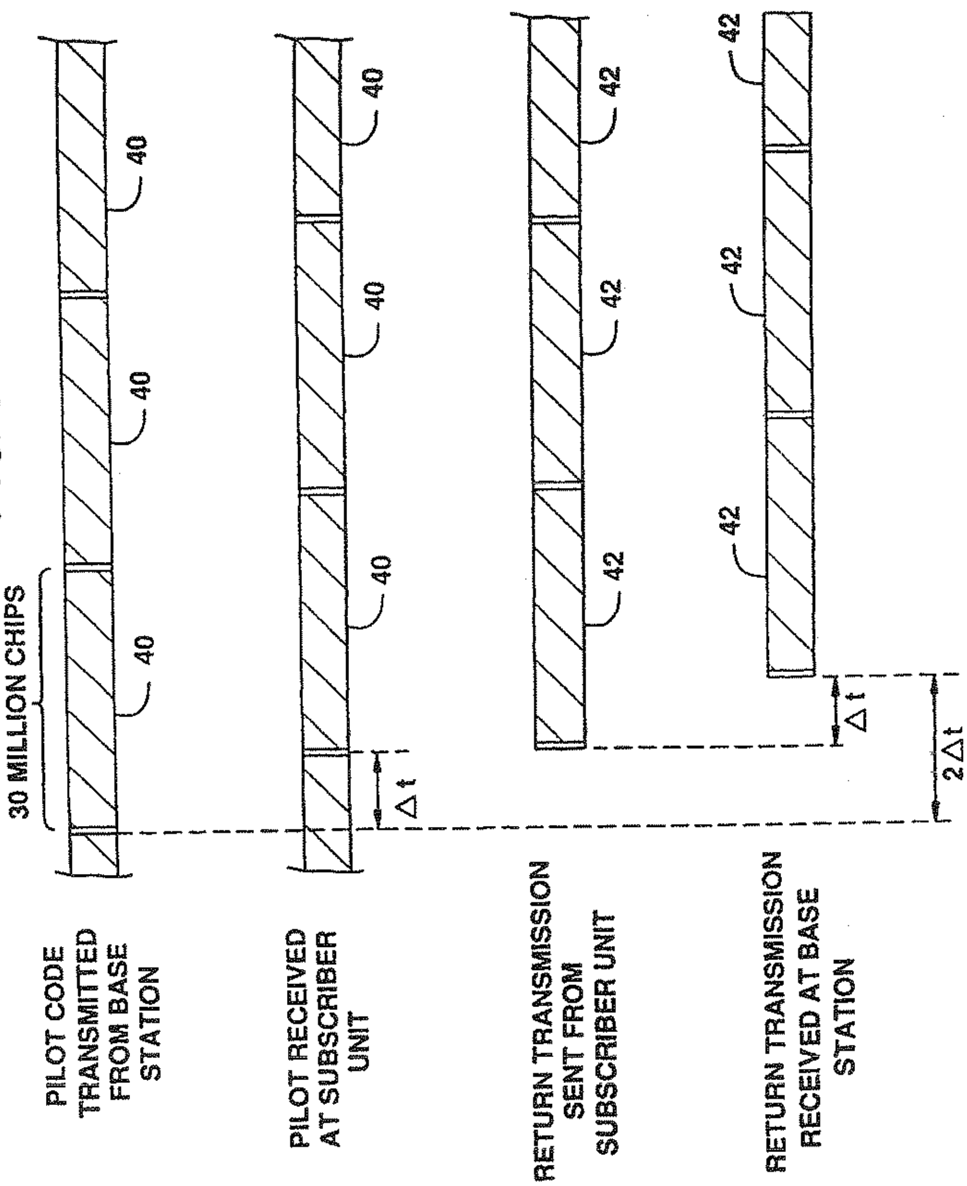

30 MILLION CHIPS
40
40
40
40
40
40
40
42
42
42
42
42
42
Δt
Δt
2Δt
PILOT CODE TRANSMITTED FROM BASE STATION
PILOT RECEIVED AT SUBSCRIBER UNIT
RETURN TRANSMISSION SENT FROM SUBSCRIBER UNIT
RETURN TRANSMISSION RECEIVED AT BASE STATION

FIG.4

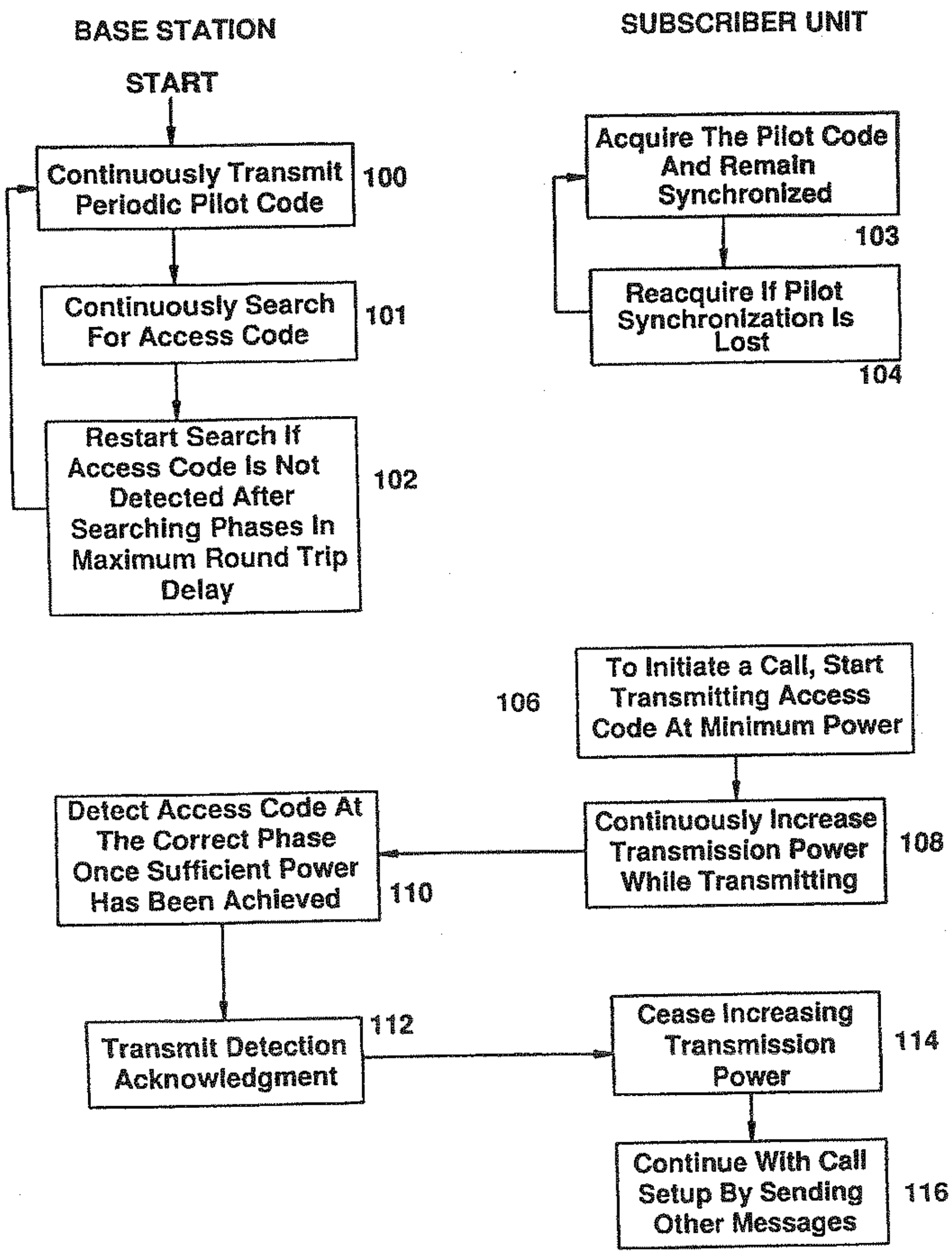
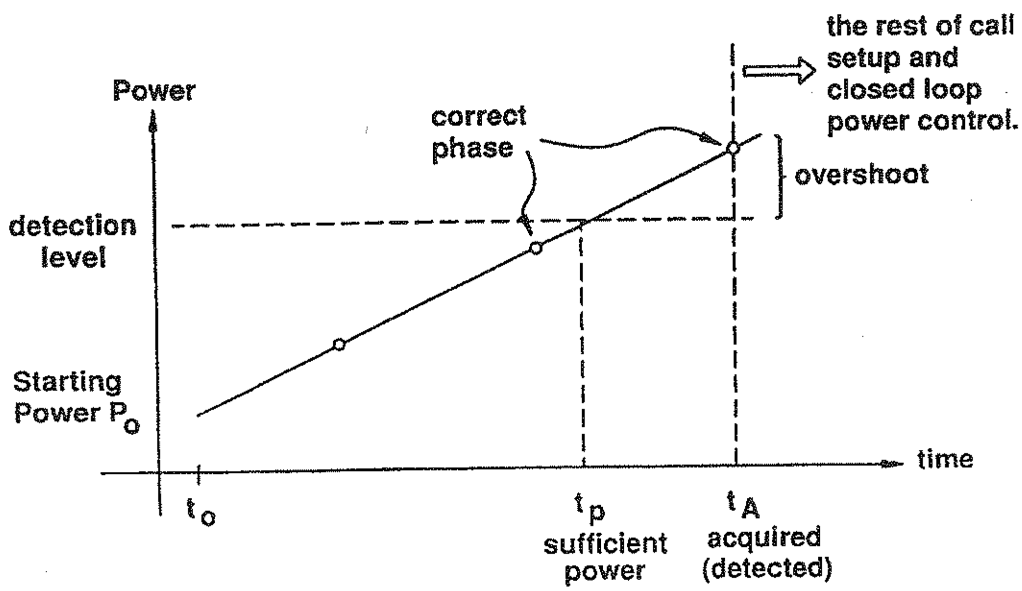
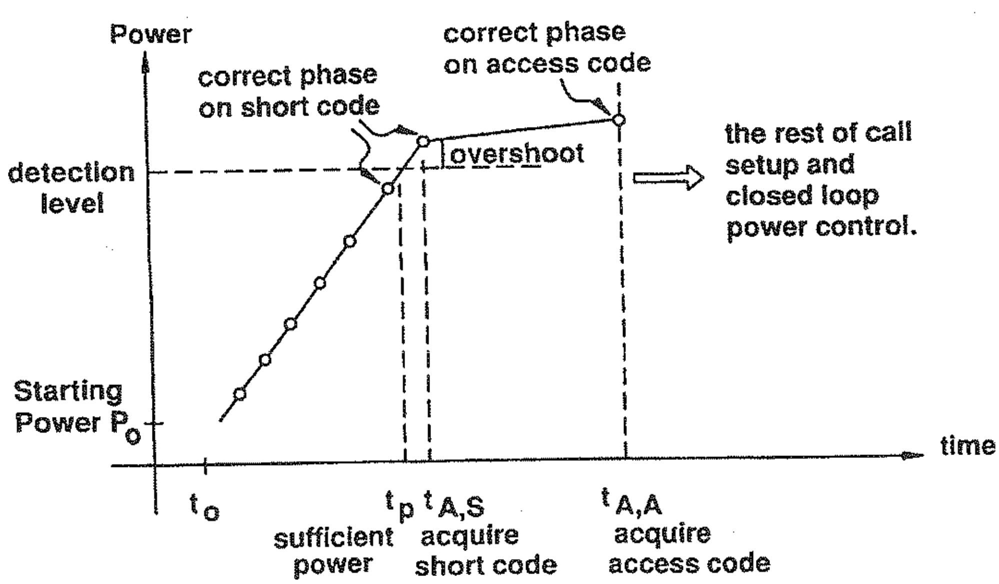

BASE STATION
SUBSCRIBER UNIT
START
Continuously Transmit Periodic Pilot Code
100
Continuously Search For Access Code
101
Restart Search If Access Code Is Not Detected After Searching Phases In Maximum Round Trip Delay
102
Acquire The Pilot Code And Remain Synchronized
103
Reacquire If Pilot Synchronization Is Lost
104
To Initiate a Call, Start Transmitting Access Code At Minimum Power
106
Continuously Increase Transmission Power While Transmitting
108
Detect Access Code At The Correct Phase Once Sufficient Power Has Been Achieved
110
Transmit Detection Acknowledgment
112
Cease Increasing Transmission Power
114
Continue With Call Setup By Sending Other Messages
116

FIG.5



Power
correct phase
the rest of call setup and closed loop power control.
overshoot
detection level
Starting Power P_o
time
t_o
t_p sufficient power
t_A acquired (detected)

FIG.7



Power
correct phase on short code
correct phase on access code
overshoot
the rest of call setup and closed loop power control.
detection level
Starting Power P_o
time
t_o
t_p sufficient power
$t_{A,S}$ acquire short code
$t_{A,A}$ acquire access code

FIG.6A

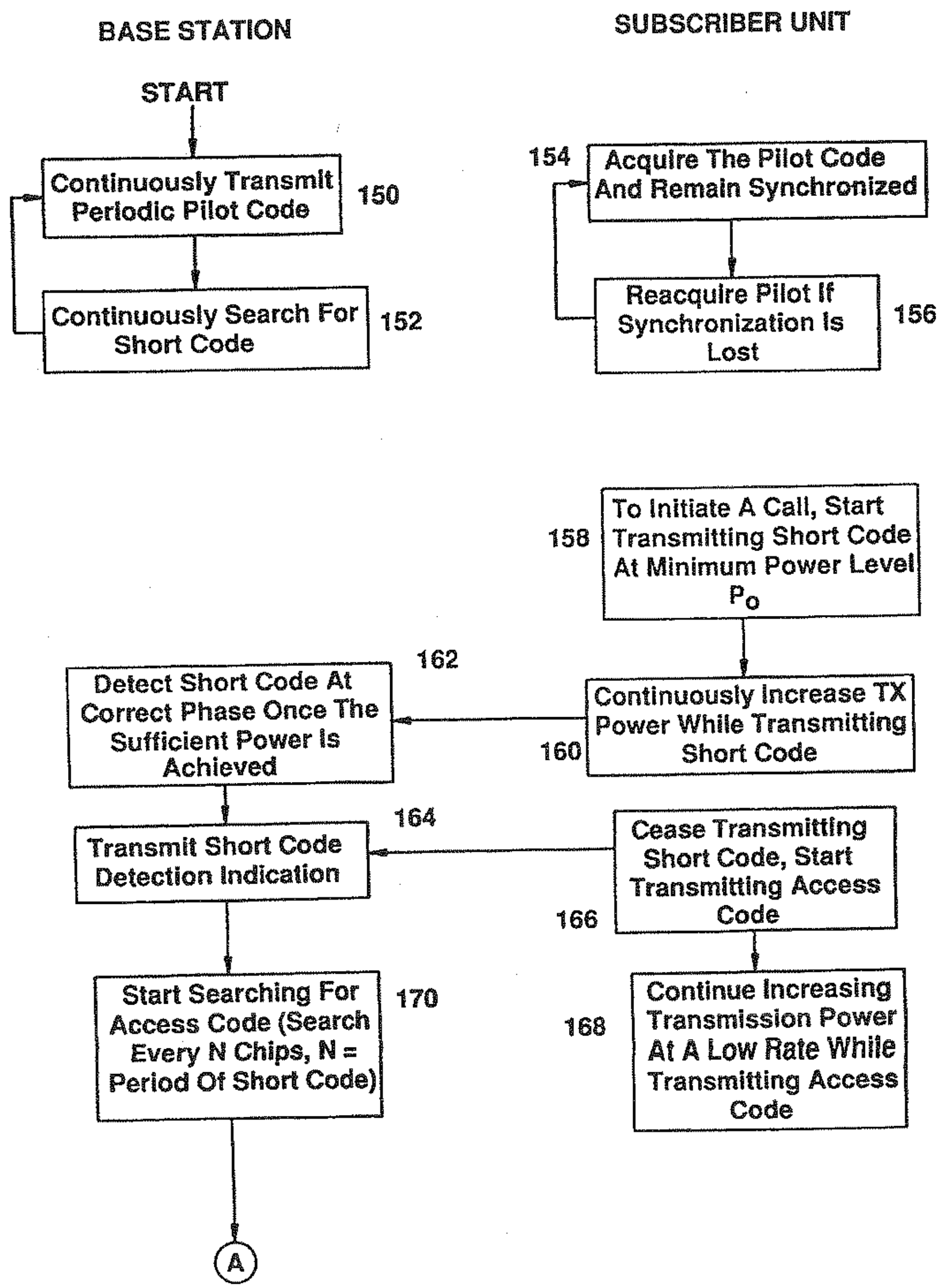

BASE STATION
SUBSCRIBER UNIT
START
Continuously Transmit Periodic Pilot Code
150
Continuously Search For Short Code
152
154
Acquire The Pilot Code And Remain Synchronized
Reacquire Pilot If Synchronization Is Lost
156
158
To Initiate A Call, Start Transmitting Short Code At Minimum Power Level P_o
162
Detect Short Code At Correct Phase Once The Sufficient Power Is Achieved
Continuously Increase TX Power While Transmitting Short Code
160
164
Transmit Short Code Detection Indication
Cease Transmitting Short Code, Start Transmitting Access Code
166
Start Searching For Access Code (Search Every N Chips, N = Period Of Short Code)
170
168
Continue Increasing Transmission Power At A Low Rate While Transmitting Access Code
A

FIG.6B

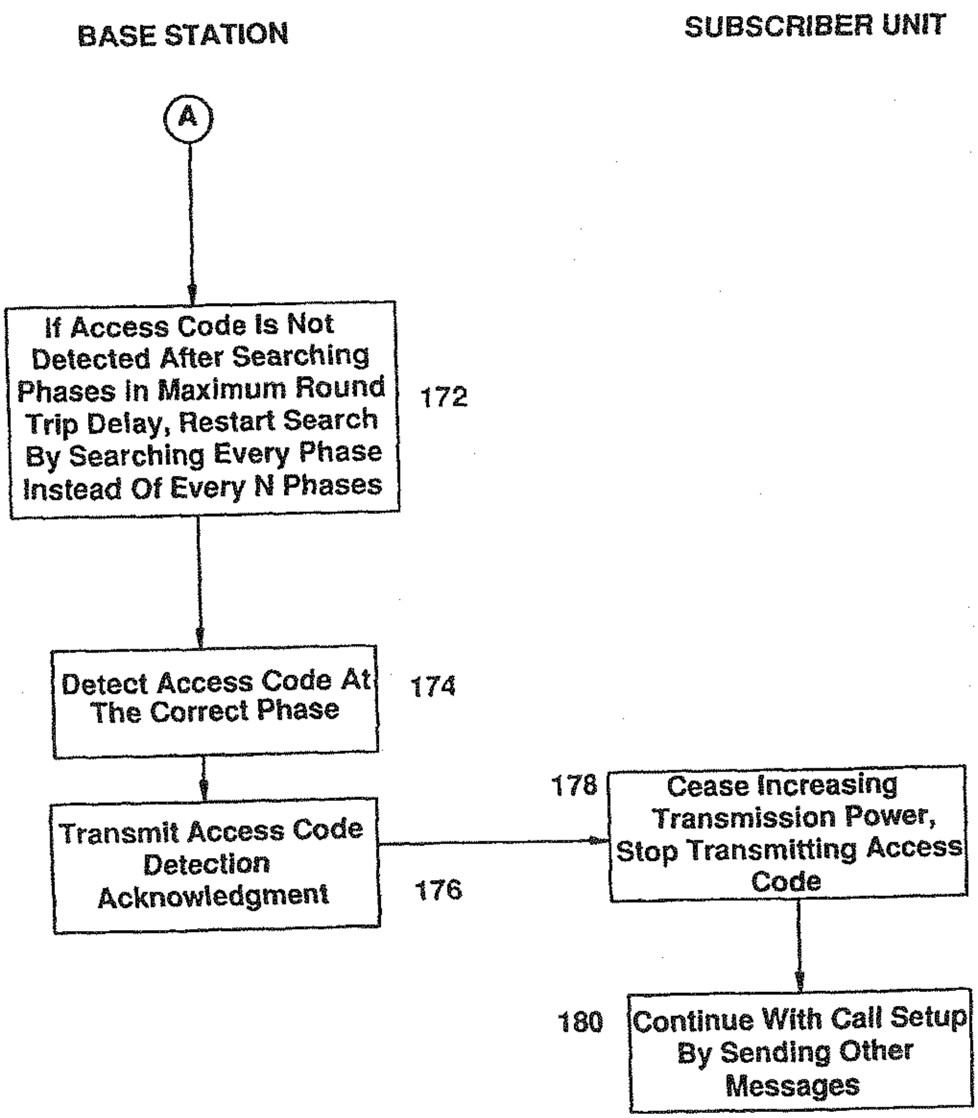
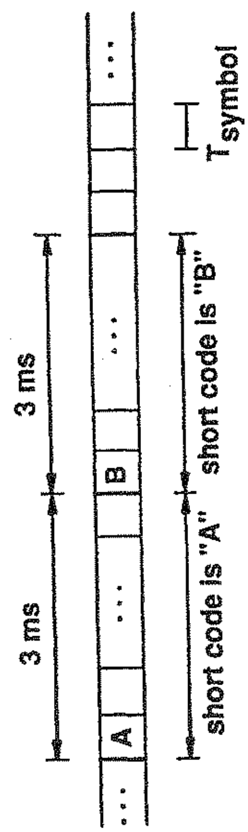
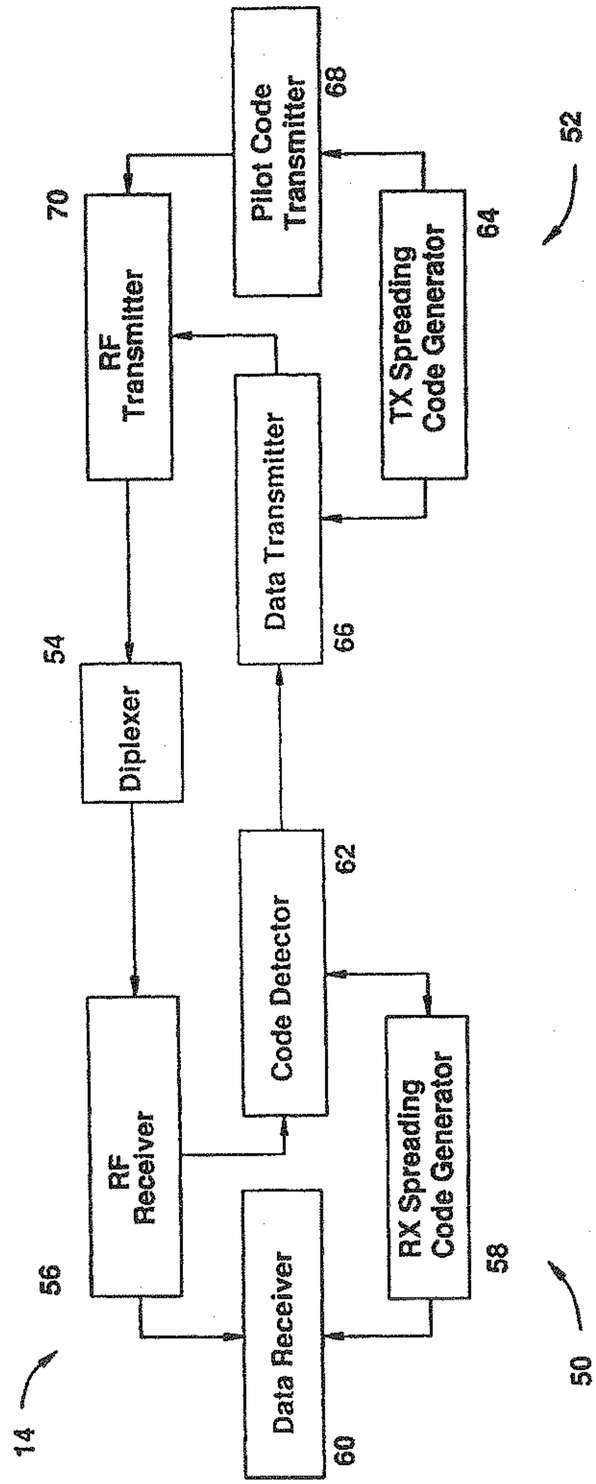

BASE STATION
SUBSCRIBER UNIT
A
If Access Code Is Not Detected After Searching Phases In Maximum Round Trip Delay, Restart Search By Searching Every Phase Instead Of Every N Phases
172
Detect Access Code At The Correct Phase
174
Transmit Access Code Detection Acknowledgment
176
178
Cease Increasing Transmission Power, Stop Transmitting Access Code
180
Continue With Call Setup By Sending Other Messages

FIG.8



3 ms
3 ms
A
B
short code is "A"
short code is "B"
T_{symbol}

FIG.9



Pilot Code Transmitter
68
70
RF Transmitter
TX Spreading Code Generator
64
52
Data Transmitter
66
54
Diplexer
Code Detector
62
RF Receiver
RX Spreading Code Generator
58
56
Data Receiver
60
14
50

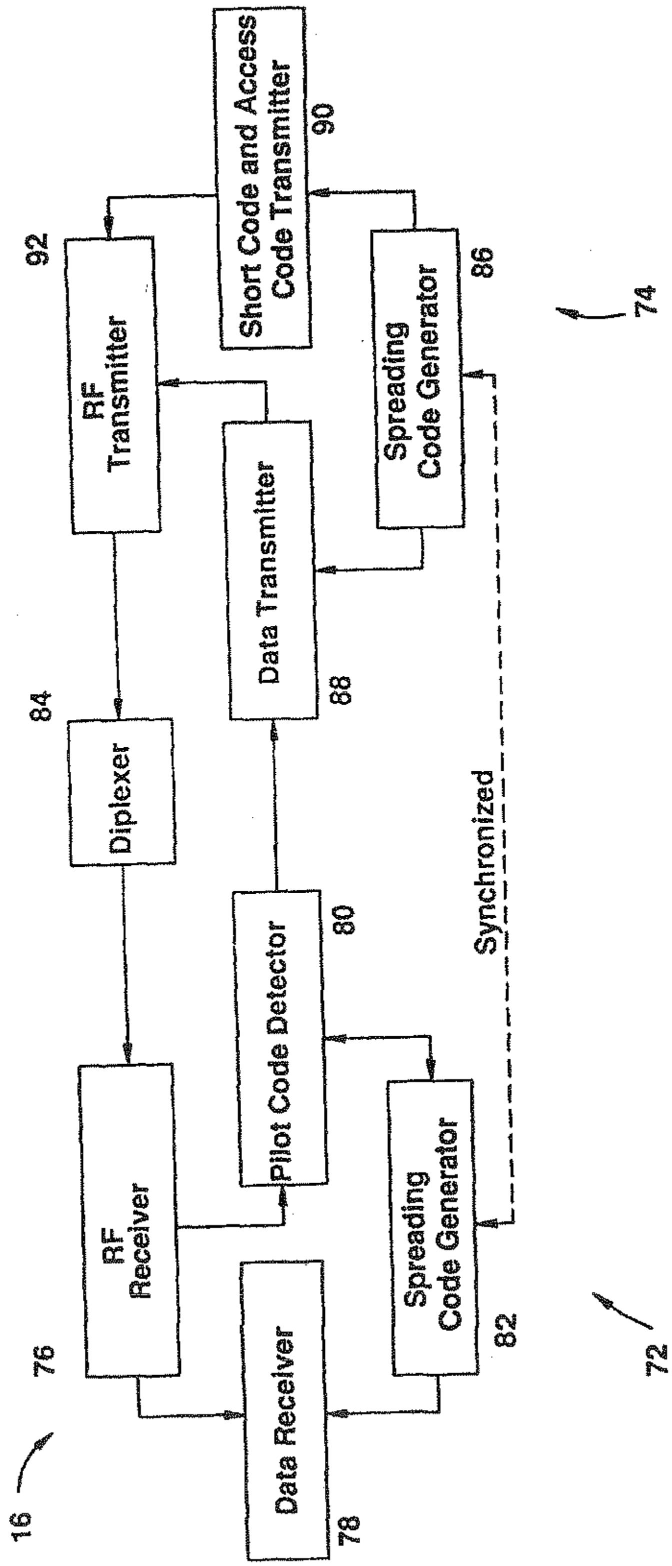

Short Code and Access Code Transmitter
90
92
RF Transmitter
Spreading Code Generator
86
74
Data Transmitter
88
84
Diplexer
Synchronized
80
Pilot Code Detector
RF Receiver
Spreading Code Generator
82
72
76
Data Receiver
78
16

FIG. 10

FIG.11A

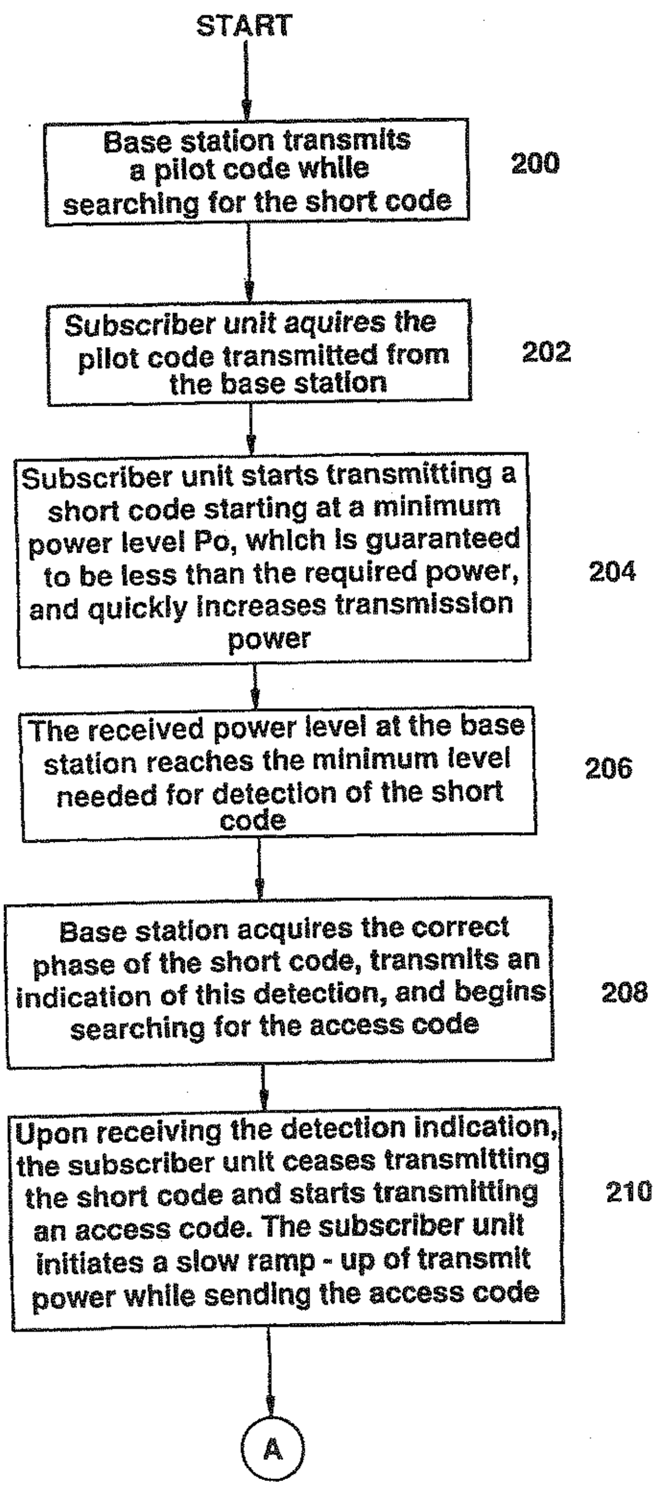
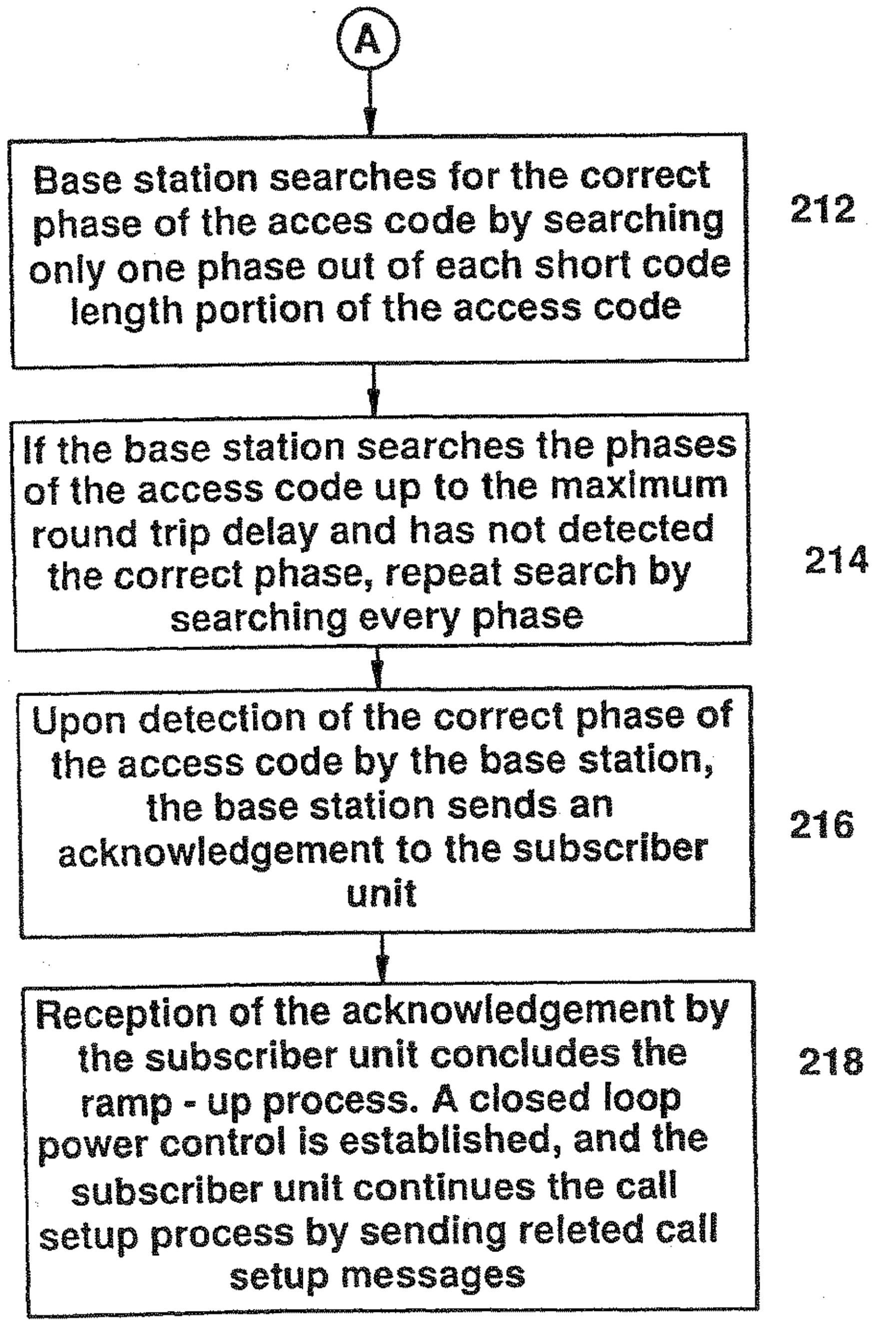

START
Base station transmits a pilot code while searching for the short code
200
Subscriber unit aquires the pilot code transmitted from the base station
202
Subscriber unit starts transmitting a short code starting at a minimum power level Po, which is guaranteed to be less than the required power, and quickly increases transmission power
204
The received power level at the base station reaches the minimum level needed for detection of the short code
206
Base station acquires the correct phase of the short code, transmits an indication of this detection, and begins searching for the access code
208
Upon receiving the detection indication, the subscriber unit ceases transmitting the short code and starts transmitting an access code. The subscriber unit initiates a slow ramp - up of transmit power while sending the access code
210
A

FIG.11B


A
Base station searches for the correct phase of the acces code by searching only one phase out of each short code length portion of the access code
212
If the base station searches the phases of the access code up to the maximum round trip delay and has not detected the correct phase, repeat search by searching every phase
214
Upon detection of the correct phase of the access code by the base station, the base station sends an acknowledgement to the subscriber unit
216
Reception of the acknowledgement by the subscriber unit concludes the ramp - up process. A closed loop power control is established, and the subscriber unit continues the call setup process by sending releted call setup messages
218

METHOD OF CONTROLLING INITIAL POWER RAMP-UP IN CDMA SYSTEMS BY USING SHORT CODES

CROSS REFERENCE TO RELATED APPLICATION

This application is being filed concurrently with an application entitled Code Division Multiple Access (CDMA) System and Method which is herein incorporated by reference as if fully set forth.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to CDMA communication systems. More specifically, the present invention relates to a CDMA communication system which utilizes the transmission of short codes from subscriber units to a base station to reduce the time required for the base station to detect the signal from a subscriber unit. The improved detection time allows a faster ramp-up of the initial transmit power from the subscriber units while reducing the unnecessary power overshoot.

2. Description of Related Art

The use of wireless telecommunication systems has grown dramatically in the last decade as the reliability and capacity of the systems have improved. Wireless communication systems are being utilized in a variety of applications where land line based systems are impractical or impossible to use. Applications of wireless communications include cellular phone communications, communications in remote locations, and temporary communications for disaster recovery. Wireless communication systems have also become an economically viable alternative to replacing aging telephone lines and outdated telephone equipment.

The portion of the RF spectrum available for use by wireless communication systems is a critical resource. The RF spectrum must be shared among all commercial, governmental and military applications. There is a constant desire to improve the efficiency of wireless communication systems in order to increase system capacity.

Code division multiple access (CDMA) wireless communication systems have shown particular promise in this area. Although more traditional time division multiple access (TDMA) and frequency division multiple access (FDMA) systems have improved using the latest technological advances, CDMA systems, in particular Broadband Code Division Multiple Access™ (B-CDMA™) systems, have significant advantages over TDMA and FDMA systems. This efficiency is due to the improved coding and modulation density, interference rejection and multipath tolerance of B-CDMA™ systems, as well as reuse of the same spectrum in every communication cell. The format of CDMA communication signals also makes it extremely difficult to intercept calls, thereby ensuring greater privacy for callers and providing greater immunity against fraud.

In a CDMA system, the same portion of the frequency spectrum is used for communication by all subscriber units. Each subscriber unit's baseband data signal is multiplied by a code sequence, called the "spreading code" which has a much higher rate than the data. The ratio of the spreading code rate to the data symbol rate is called the "spreading factor" or the "processing gain". This coding results in a much wider transmission spectrum than the spectrum of the baseband data signal, hence the technique is called "spread spectrum". Subscriber units and their communications can

be discriminated by assigning a unique spreading code to each communication link which is called a CDMA channel. Since all communications are sent over the same frequency band, each CDMA communication overlaps communications from other subscriber units and noise-related signals in both frequency and time.

The use of the same frequency spectrum by a plurality of subscriber units increases the efficiency of the system. However, it also causes a gradual degradation of the performance of the system as the number of users increase. Each subscriber unit detects communication signals with its unique spreading code as valid signals and all other signals are viewed as noise. The stronger the signal from a subscriber unit arrives at the base station, the more interference the base station experiences when receiving and demodulating signals from other subscriber units. Ultimately, the power from one subscriber unit may be great enough to terminate communications of other subscriber units. Accordingly, it is extremely important in wireless CDMA communication systems to control the transmission power of all subscriber units. This is best accomplished by using a closed loop power control algorithm once a communication link is established. A detailed explanation of such a closed loop algorithm is disclosed in U.S. Patent Application entitled Code Division Multiple Access (CDMA) System and Method filed concurrently herewith, which is incorporated by reference as if fully set forth.

The control of transmission power is particularly critical when a subscriber unit is attempting to initiate communications with a base station and a power control loop has not yet been established. Typically, the transmission power required from a subscriber unit changes continuously as a function of the propagation loss, interference from other subscribers, channel noise, fading and other channel characteristics. Therefore, a subscriber unit does not know the power level at which it should start transmitting. If the subscriber unit begins transmitting at a power level that is too high, it may interfere with the communications of other subscriber units and may even terminate the communications of other subscriber units. If the initial transmission power level is too low, the subscriber unit will not be detected by the base station and a communication link will not be established.

There are many methods for controlling transmission power in a CDMA communication system. For example, U.S. Pat. No. 5,056,109 (Gilhousen et al.) discloses a transmission power control system wherein the transmission power of the subscriber unit is based upon periodic signal measurements from both the subscriber unit and the base station. The base station transmits a pilot signal to all subscriber units which analyze the received pilot signal, estimate the power loss in the transmitted signal and adjust their transmission power accordingly. Each subscriber unit includes a non-linear loss output filter which prevents sudden increases in power which would cause interference to other subscriber units. This method is too complex to permit a base station to quickly acquire a subscriber unit while limiting the interference to other subscriber units. In addition, the propagation losses, interference and noise levels experienced in a forward link (transmission from the base station to a subscriber unit) is often not the same as in a reverse link (transmission from a subscriber unit to the base station). Reverse link power estimates based on forward link losses are not precise.

Many other types of prior art transmission power control systems require complex control signaling between communicating units or preselected transmission values to control transmission power. These power control techniques are inflexible and often impractical to implement.

Accordingly, there is a need for an efficient method of controlling the initial ramp-up of transmission power by subscriber units in a wireless CDMA communication system.

SUMMARY OF THE INVENTION

The present invention comprises a novel method of controlling transmission power during the establishment of a channel in a CDMA communication system by utilizing the transmission of a short code from a subscriber unit to a base station during initial power ramp-up. The short code is a sequence for detection by the base station which has a much shorter period than a conventional spreading code. The ramp-up starts from a power level that is guaranteed. to be lower than the required power level for detection by the base station. The subscriber unit quickly increases transmission power while repeatedly transmitting the short code until the signal is detected by the base station. Once the base station detects the short code, it sends an indication to. the subscriber unit to cease increasing transmission power. The use of short codes limits power overshoot and interference to other subscriber stations and permits the base station to quickly synchronize to the spreading code used by the subscriber unit.

Accordingly, it is an object of the present invention to provide an improved technique for controlling power ramp-up during establishment of a communication channel between a CDMA subscriber unit and base station.

Other objects and advantages of the present invention will become apparent after reading the description of a presently preferred embodiment.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic overview of a code division multiple access communication system in accordance with the present invention;

FIG. 2 is a diagram showing the operating range of a base station;

FIG. 3 is a timing diagram of communication signals between a base station and a subscriber unit;

FIG. 4 is a flow diagram of the establishment of a communication channel between a base station and a subscriber unit;

FIG. 5 is a graph of the transmission power output from a subscriber unit;

FIGS. 6A and 6B are flow diagrams of the establishment of a communication channel between a base station and a subscriber unit in accordance with the preferred embodiment of the present invention using short codes;

FIG. 7 is a graph of the transmission power output from a subscriber unit using short codes;

FIG. 8 shows the adaptive selection of short codes;

FIG. 9 is a block diagram of a base station in accordance with the present invention;

FIG. 10 is a block diagram of the subscriber unit in accordance with the present invention; and

FIGS. 11A and 11B are flow diagrams of the ramp-up procedure implemented in accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The preferred embodiment will be described with reference to the drawing figures where identical numerals represent similar elements throughout.

A communication network 10 embodying the present invention is shown in FIG. 1. The communication network 10 generally comprises one or more base stations 14, each of which is in wireless communication with a plurality of subscriber units 16, which may be fixed or mobile. Each subscriber unit 16 communicates with either the closest base station 14 or the base station 14 which provides the strongest communication signal. The base stations 14 also communicate with a base station controller 20, which coordinates communications among base stations 14. The communication network 10 may also be connected to a public switched telephone network (PSTN) 22, wherein the base station controller 20 also coordinates communications between the base stations 14 and the PSTN 22. Preferably, each base station 14 communicates with the base station controller 20 over a wireless link, although a land line may also be provided. A land line is particularly applicable when a base station 14 is in close proximity to the base station controller 20.

The base station controller 20 performs several functions. Primarily, the base station controller 20 provides all of the operations, administrative and maintenance (OA&M) signaling associated with establishing and maintaining all of the wireless communications between the subscriber units 16, the base stations 14, and the base station controller 20. The base station controller 20 also provides an interface between the wireless communication system 10 and the PSTN 22. This interface includes multiplexing and demultiplexing of the communication signals that enter and leave the system 10 via the base station controller 20. Although the wireless communication system 10 is shown employing antennas to transmit RF signals, one skilled in the art should recognize that communications may be accomplished via microwave or satellite uplinks. Additionally, the functions of the base station controller 20 may be combined with a base station 14 to form a "master base station".

Referring to FIG. 2, the propagation of signals between a base station 14 and a plurality of subscriber units 16 is shown. A two-way communication channel (link) 18 comprises a signal transmitted 20 (Tx) from the base station 14 to the subscriber unit 16 and a signal received 22 (Rx) by the base station 14 from the subscriber unit 16. The Tx signal 20 is transmitted from the base station 14 and is received by the subscriber unit 16 after a propagation delay Δt. Similarly, the Rx signal originates at the subscriber unit 16 and terminates at the base station 14 after a further propagation delay Δt. Accordingly, the round trip propagation delay is 2Δt. In the preferred embodiment, the base station 14 has an operating range of approximately 30 kilometers. The round trip propagation delay 24 associated with a subscriber unit 16 at the maximum operating range is 200 microseconds.

It should be apparent to those of skill in the art that the establishment of a communication channel between a base station and a subscriber unit is a complex procedure involving many tasks performed by the base station and the subscriber unit which are outside the scope of the present invention. The present invention is directed to initial power ramp-up and synchronization during the establishment of a communication channel.

Referring to FIG. 3, the signaling between a base station 14 and a subscriber unit 16 is shown. In accordance with the present invention, the base station 14 continuously transmits a pilot code 40 to all of the subscriber units 16 located within the transmitting range of the base station 14. The pilot code 40 is a spreading code which carries no data bits. The pilot code 40 is used for subscriber unit 16 acquisition and synchronization, as well as for determining the parameters of the adaptive matched filter used in the receiver.

The subscriber unit 16 must acquire the pilot code 40 transmitted by the base station 14 before it can receive or transmit any data. Acquisition is the process whereby the subscriber unit 16 aligns its locally generated spreading code with the received pilot code 40. The subscriber unit 16 searches through all of the possible phases of the received pilot code 40 until it detects the correct phase, (the beginning of the pilot code 40).

The subscriber unit 16 then synchronizes its transmit spreading code to the received pilot code 40 by aligning the beginning of its transmit spreading code to the beginning of the pilot code 40. One implication of this receive and transmit synchronization is that the subscriber unit 16 introduces no additional delay as far as the phase of the spreading codes are concerned. Accordingly, as shown in FIG. 3, the relative delay between the pilot code 40 transmitted from the base station 14 and the subscriber unit's transmit spreading code 42 received at the base station 14 is $2\Delta t$, which is solely due to the round trip propagation delay.

In the preferred embodiment, the pilot code is 29,877,120 chips in length and takes approximately 2 to 5 seconds to transmit, depending on the spreading factor. The length of the pilot code 40 was chosen to be a multiple of the data symbol no matter what kind of data rate or bandwidth is used. As is well known by those of skill in the art, a longer pilot code 40 has better randomness properties and the frequency response of the pilot code 40 is more uniform. Additionally, a longer pilot code 40 provides low channel cross correlation, thus increasing the capacity of the system 10 to support more subscriber units 16 with less interference. The use of a long pilot code 40 also supports a greater number of random short codes. For synchronization purposes, the pilot code 40 is chosen to have the same period as all of the other spreading codes used by the system 10. Thus, once a subscriber unit 16 acquires the pilot code 40, it is synchronized to all other signals transmitted from the base station 14.

During idle periods, when a call is not in progress or pending, the subscriber unit 16 remains synchronized to the base station 14 by periodically reacquiring the pilot code 40. This is necessary for the subscriber unit 16 to receive and demodulate any downlink transmissions, in particular paging messages which indicate incoming calls.

When a communication link is desired, the base station 14 must acquire the signal transmitted from the subscriber unit 16 before it can demodulate the data. The subscriber unit 16 must transmit an uplink signal for acquisition by the base station 14 to begin establishing the two-way communication link. A critical parameter in this procedure is the transmission power level of the subscriber unit 16. A transmission power level that is too high can impair communications in the whole service area, whereas a transmission power level that is too low can prevent the base station 14 from detecting the uplink signal.

In a first embodiment of the present invention the subscriber unit 16 starts transmitting at a power level guaranteed to be lower than what is required and increases transmission power output until the correct power level is achieved. This avoids sudden introduction of a strong interference, hence improving system 10 capacity.

The establishment of a communication channel in accordance with the present invention and the tasks performed by the base station 14 and a subscriber unit 16 are shown in FIG. 4. Although many subscriber units 16 may be located within the operating range of the base station 14, reference will be made hereinafter to a single subscriber unit 16 for simplicity in explaining the operation of the present invention.

The base station 14 begins by continuously transmitting a periodic pilot code 40 to all subscriber units 16 located within the operating range of the base station 14 (step 100). As the base station 14 transmits the pilot code 40 (step 100), the base station 14 searches (step 101) for an "access code" 42 transmitted by a subscriber unit 16. The access code 42 is a known spreading code transmitted from a subscriber unit 16 to the base station 14 during initiation of communications and power ramp-up. The base station 14 must search through all possible phases (time shifts) of the access code 42 transmitted from the subscriber unit 16 in order to find the correct phase. This is called the "acquisition" or the "detection" process (step 101). The longer the access code 42, the longer it takes for the base station 14 to search through the phases and acquire the correct phase.

As previously explained, the relative delay between signals transmitted from the base station 14 and return signals received at the base station 14 corresponds to the round trip propagation delay $2\Delta t$. The maximum delay occurs at the maximum operating range of the base station 14, known as the cell boundary. Accordingly, the base station 14 must search up to as many code phases as there are in the maximum round trip propagation delay, which is typically less code phases than there are in a code period.

For a data rate Rb and spreading code rate Rc, the ratio $L=Rc/Rb$ is called the spreading factor or the processing gain. In the preferred embodiment of the present invention, the cell boundary radius is 30 km, which corresponds to approximately between 1000 and 2500 code phases in the maximum round trip delay, depending on the processing gain.

If the base station 14 has not detected the access code after searching through the code phases corresponding to the maximum round trip delay the search is repeated starting from the phase of the pilot code 40 which corresponds to zero delay (step 102).

During idle periods, the pilot code 40 from the base station 14 is received at the subscriber unit 16 which periodically synchronizes its transmit spreading code generator thereto (step 103). If synchronization with the pilot code 40 is lost, the subscriber unit 16 reacquires the pilot code 40 and resynchronizes (step 104).

When it is desired to initiate a communication link, the subscriber unit 16 starts transmitting the access code 42 back to the base station 14 (step 106). The subscriber unit 16 continuously increases the transmission power while retransmitting the access code 42 (step 108) until it receives an acknowledgment from the base station 14. The base station 14 detects the access code 42 at the correct phase once the minimum power level for reception has been achieved (step 110). The base station 14 subsequently transmits an access code detection acknowledgment signal (step 112) to the subscriber unit 16. Upon receiving the acknowledgment, the subscriber unit ceases the transmission power increase (step 114). With the power ramp-up completed, closed loop power control and call setup signaling is performed (step 116) to establish the two-way communication link.

Although this embodiment limits subscriber unit 16 transmission power, acquisition of the subscriber unit 16 by the base station 14 in this manner may lead to unnecessary power overshoot from the subscriber unit 16, thereby reducing the performance of the system 10.

The transmission power output profile of the subscriber unit 16 is shown in FIG. 5. At t_0, the subscriber unit 16 starts transmitting at the starting transmission power level P_0,

which is a power level guaranteed to be less than the power level required for detection by the base station **14**. The subscriber unit **16** continually increases the transmission power level until it receives the detection indication from the base station **14**. For the base station **14** to properly detect the access code **42** from the subscriber unit **16** the access code **42** must: 1) be received at a sufficient power level; and 2) be detected at the proper phase. Accordingly, referring to FIG. **5**, although the access code **42** is at a sufficient power level for detection by the base station **14** at t_p, the base station **14** must continue searching for the correct phase of the access code **42** which occurs at t_A.

Since the subscriber unit **16** continues to increase the output transmission power level until it receives the detection indication from the base station **14**, the transmission power of the access code **42** exceeds the power level required for detection by the base station **14**. This causes unnecessary interference to all other subscriber units **16**. If the power overshoot is too large, the interference to other subscriber units **16** may be so severe as to terminate ongoing communications of other subscriber units **16**.

The rate that the subscriber unit **16** increases transmission power to avoid overshoot may be reduced, however, this results in a longer call setup time. Those of skill in the art would appreciate that adaptive ramp-up rates can also be used, yet these rates have shortcomings and will not appreciably eliminate power overshoot in all situations.

The preferred embodiment of the present invention utilizes "short codes" and a two-stage communication link establishment procedure to achieve fast power ramp-up without large power overshoots. The spreading code transmitted by the subscriber unit **16** is much shorter than the rest of the spreading codes (hence the term short code), so that the number of phases is limited and the base station **14** can quickly search through the code. The short code used for this purpose carries no data.

The tasks performed by the base station **14** and the subscriber unit **16** to establish a communication channel using short codes in accordance with the preferred embodiment of the present invention are shown in FIGS. 6A and 6B. During idle periods, the base station **14** periodically and continuously transmits the pilot code to all subscriber units **16** located within the operating range of the base station **14** (step **150**). The base station **14** also continuously searches for a short code transmitted by the subscriber unit **16** (step **152**). The subscriber unit **16** acquires the pilot code and synchronizes its transmit spreading code generator to the pilot code. The subscriber unit **16** also periodically checks to ensure it is synchronized. If synchronization is lost, the subscriber unit **16** reacquires the pilot signal transmitted by the base station (step **156**).

When a communication link is desired, the subscriber unit **16** starts transmitting a short code at the minimum power level p_0 (step **158**) and continuously increases the transmission power level while retransmitting the short code (step **160**) until it receives an acknowledgment from the base station **14** that the short code has been detected by the base station **14**.

The access code in the preferred embodiment, as previously described herein, is approximately 30 million chips in length. However, the short code is much smaller. The short code can be chosen to be any length that is sufficiently short to permit quick detection. There is an advantage in choosing a short code length such that it divides the access code period evenly. For the access code code described herein, the short code is preferably chosen to be 32, 64 or 128 chips in length. Alternatively, the short code may be as short as one symbol length, as will be described in detail hereinafter.

Since the start of the short code and the start of the access code are synchronized, once the base station **14** acquires the short code, the base station **14** knows that the corresponding phase of the access code is an integer multiple of N chips from the phase of the short code where N is the length of the short code. Accordingly, the base station **14** does not have to search all possible phases corresponding to the maximum round trip propagation delay.

Using the short code, the correct phase for detection by the base station **14** occurs much more frequently. When the minimum power level for reception has been achieved, the short code is quickly detected (step **162**) and the transmission power overshoot is limited. The transmission power ramp-up rate may be significantly increased without concern for a large power overshoot. In the preferred embodiment of the present invention, the power ramp-up rate using the short code is 1 dB per millisecond.

The base station **14** subsequently transmits a short code detection indication signal (step **164**) to the Subscriber unit **16** which enters the second stage of the power ramp-up upon receiving this indication. In this stage, the subscriber unit **16** ceases transmitting the short code (step **166**) and starts continuously transmitting a periodic access code (step **166**). The subscriber unit **16** continues to ramp-up its transmission power while transmitting the access code, however the ramp-up rate is now much lower than the previous ramp-up rate used with the short code (step **168**). The ramp-up rate with the access code is preferably 0.05 dB per millisecond. The slow ramp-up avoids losing synchronization with the base station **14** due to small changes in channel propagation characteristics.

At this point, the base station **14** has detected the short code at the proper phase and power level (step **162**). The base station **14** must now synchronize to the access code which is the same length as all other spreading codes and much longer than the short code. Utilizing the short code, the base station **14** is able to detect the proper phase of the access code much more quickly. The base station **14** begins searching for the proper phase of the access code (step **170**). However, since the start of the access code is synchronized with the start of the short code, the base station **14** is only required to search every N chips; where N=the length of the short code. In summary, the base station **14** quickly acquires the access code of the proper phase and power level by: 1) detecting the short code; and 2) determining the proper phase of the access code by searching every N chips of the access code from the beginning of the short code.

If the proper phase of the access code has not been detected after searching the number of phases in the maximum round trip delay the base station **14** restarts the search for the access code by searching every chip instead of every N chips (step **172**). When the proper phase of the access code has been detected (step **174**) the base station **14** transmits an access code detection acknowledgment (step **176**) to the subscriber unit **16** which ceases the transmission power increase (step **178**) upon receiving this acknowledgment. With the power ramp-up completed, closed loop power control and call setup signaling is performed (step **180**) to establish the two-way communication link.

Referring to FIG. 7, although the starting power level P_0 is the same as in the prior embodiment, the subscriber unit **16** may ramp-up the transmission power level at a much higher rate by using a short code. The short code is quickly detected after the transmission power level surpasses the

minimum detection level, thus minimizing the amount of transmission power overshoot.

Although the same short code may be reused by the subscriber unit 16, in the preferred embodiment of the present invention the short codes are dynamically selected and updated in accordance with the following procedure. Referring to FIG. 8, the period of the short code is equal to one symbol length and the start of each period is aligned with a symbol boundary. The short codes are generated from a regular length spreading code. A symbol length portion from the beginning of the spreading code is stored and used as the short code for the next 3 milliseconds. Every 3 milliseconds, a new symbol length portion of the spreading code replaces the old short code. Since the spreading code period is an integer multiple of 3 milliseconds, the same short codes are repeated once every period of the spreading code.

Periodic updating of the short code averages the interference created by the short code over the entire spectrum. A detailed description of the selection and updating of the short codes is outside the scope of this invention. However, such a detailed description is disclosed in the related application U.S. Patent Appln. entitled Code Division Multiple Access (CDMA) System and Method.

A block diagram of the base station 14 is shown in FIG. 9. Briefly described, the base station 14 comprises a receiver section 50, a transmitter section 52 and a diplexer 54. An RF receiver 56 receives and down-converts the RF signal received from the diplexer 54. The receive spreading code generator 58 outputs a spreading code to both the data receiver 60 and the code detector 62. In the data receiver 60, the spreading code is correlated with the baseband signal to extract the data signal which is forwarded for further processing. The received baseband signal is also forwarded to the code detector 62 which detects the access code or the short code from the subscriber unit 16 and adjusts the timing of the spreading code generator 58 to establish a communication channel 18.

In the transmitter section 52 of the base station 14, the transmit spreading code generator 64 outputs a spreading code to the data transmitter 66 and the pilot code transmitter 68. The pilot code transmitter 68 continuously transmits the periodic pilot code. The data transmitter 66 transmits the short code detect indication and access code detect acknowledgment after the code detector 62 has detected the short code or the access code respectively. The data transmitter also sends other message and data signals. The signals from the data transmitter 66 and the pilot code transmitter 68 are combined and up-converted by the RF transmitter 70 for transmission to the subscriber units 16.

A block diagram of the subscriber unit 16 is shown in FIG. 10. Briefly described, the subscriber unit 16 comprises a receiver section 72, a transmitter section 74 and a diplexer 84. An RF receiver 76 receives and down-converts the RF signal received from the diplexer 84. A pilot code detector 80 correlates the spreading code with the baseband signal to acquire the pilot code transmitted by the base station 16. In this manner, the pilot code detector 80 maintains synchronization with the pilot code. The receiver spreading code generator 82 generates and outputs a spreading code to the data receiver 78 and the pilot code detector 80. The data receiver 78 correlates the spreading code with the baseband signal to process the short code detect indication and the access code detect acknowledgment transmitted by the base station 16.

The transmitter section 74 comprises a spreading code generator 86 which generates and outputs spreading codes to a data transmitter 88 and a short code and access code transmitter 90. The short code and access code transmitter 90 transmits these codes at different stages of the power ramp-up procedure as hereinbefore described. The signals output by the data transmitter 88 and the short code and access code transmitter 90 are combined and up-converted by the RF transmitter 92 for transmission to the base station 14. The timing of the receiver spreading code generator 82 is adjusted by the pilot code detector 80 through the acquisition process. The receiver and transmitter spreading code generators 82, 86 are also synchronized.

An overview of the ramp-up procedure in accordance with the preferred current invention is summarized in FIGS. 11A and 11B. The base station 14 transmits a pilot code while searching for the short code (step 200). The subscriber unit 16 acquires the pilot code transmitted from the base station 14 (step 202), starts transmitting a short code starting at a minimum power level P_0 which is guaranteed to be less than the required power, and quickly increases transmission power (step 204). Once the received power level at the base station 14 reaches the minimum level needed for detection of the short code (step 206) the base station 14 acquires the correct phase of the short code, transmits an indication of this detection, and begins searching for the access code (step 208). Upon receiving the detection indication, the subscriber unit 16 ceases transmitting the short code and starts transmitting an access code. The subscriber unit 16 initiates a slow ramp-up of transmit power while sending the access code (step 210). The base station 14 searches for the correct phase of the access code by searching only one phase out of each short code length portion of the access code (step 212). If the base station 14 searches the phases of the access code up to the maximum round trip delay and has not detected the correct phase, the search is repeated by searching every phase (step 214). Upon detection of the correct phase of the access code by the base station 14, the base station 14 sends an acknowledgment to the subscriber unit 16 (step 216). Reception of the acknowledgment by the subscriber unit 16 concludes the ramp-up process. A closed loop power control is established, and the subscriber unit 16 continues the call setup process by sending related call setup messages (step 218).

Although the invention has been described in part by making detailed reference to the preferred embodiment, such detail is intended to be instructive rather than restrictive. It will be appreciated by those skilled in the art that many variations may be made in the structure and mode of operation without departing from the spirit and scope of the invention as disclosed in the teachings herein.

What is claimed is:

1. A method for controlling transmission power during the establishment of communications between a base station and at least one subscriber unit, the method comprising:

transmitting a periodic signal from said subscriber unit at an initial predetermined power level;

increasing said power level at a predetermined ramp-up rate;

detecting said periodic signal at said base station when a sufficient power for detection is achieved;

transmitting a signal from said base station confirming that said periodic signal has been detected;

receiving said confirmation signal at said subscriber unit; and

ceasing the increase of the power level of the transmission of said periodic signal at said predetermined power level ramp-up rate when said confirmation signal is received.

2. The method of claim 1 wherein said initial predetermined power level is lower than the power level required for detection by said base station.

3. The method of claim 2 further including increasing the power level of said signal at a second predetermined rate, said second rate being less than said first rate.

4. The method of claim 3 wherein said first rate is approximately 1.0 dB/sec and said second rate is approximately 0.05 dB/sec.

5. A network for communicating between a base station and at least one subscriber unit, the network including a system for initial power control comprising:

said subscriber unit comprising:

means for selectively transmitting at least one access code at a selected transmission power level;

means for detecting a signal from said base station confirming the receipt of said access code; and

control means, responsive to said detecting means, for varying said transmission power level; wherein said control means ceases increasing said transmission power level at a first rate upon the receipt of said confirmation signal and increases said transmission power level at a second rate after the receipt of said confirmation signal, said second rate being less than said first rate; and said base station comprising:

means for detecting transmissions from at least one said subscriber unit, said transmissions including said access code; and

transmission means, responsive to said detecting means, for transmitting a confirmation signal to said subscriber unit when said access code is detected.

6. A communication network for conducting a plurality of concurrent communications using wireless transmissions between a primary station and at least one secondary station, the network including a power control system for controlling initial transmission power; the power control system comprising:

the primary station having:

(i) means for transmitting a synchronization code;

(ii) means for detecting access codes transmitted from said at least one secondary station; and

(iii) means for generating a confirmation signal, said generating means being responsive to said detecting means; and a first secondary station having:

(i) means for receiving the synchronization information from the primary station;

(ii) means for transmitting an access signal at a first transmission power level; and

(iii) means for increasing said transmission power level until said confirmation signal from said primary station is received whereupon the transmission of said synchronization code ceases.

7. A method for controlling transmission power ramp-up during establishment of communications between a base station and at least one subscriber unit, the method comprising:

transmitting from said subscriber unit a periodic signal at a predetermined power level, said power level being sufficiently low such that it will not be detected by said base station;

steadily increasing the power level of said signal at a predefined ramp-up rate;

detecting at said base station, the correct phase of said periodic signal when the signal achieves a sufficient power for detection by said base station;

transmitting, from said base station, a confirmation signal that said periodic signal has been detected;

receiving, at said subscriber unit, said confirmation signal, and;

ceasing the transmission of said periodic signal at the predetermined power level ramp-up rate at said subscriber unit when said confirmation signal is received.

8. The method of claim 7 further including increasing the power level of said signal at a second predefined ramp-up rate; said second ramp-up rate being less than said first ramp-up rate.

9. The method of claim 8 wherein said first ramp-up rate is approximately 1.0 dB/sec and said second ramp-up rate is approximately 0.05 dB/sec.

10. A communication system for communicating between a base station and at least one subscriber unit, said communication system including a system for initial power control, said power control system comprising:

said subscriber unit comprising:

means for periodically transmitting a short access code having a predetermined length to said base station; said short access code being transmitted at a first power level;

means for increasing said power level at a first power ramp-up rate;

means for detecting a transmission from said base station which confirms the receipt of said short access code at said base station; and

means, responsive to said detecting means, for ceasing increase of said power level at said first power ramp-up rate and periodically transmitting a long access code a second increasing power ramp-up rate; said long access code having a predetermined length which is an even multiple of said short access code said second ramp-up rate being less than said first power increase rate; and said base station comprising:

means for detecting transmissions from at least one said subscriber unit including said short and long access codes; and

transmission means, responsive to said detecting means, for transmitting a confirmation signal to said subscriber unit when said access codes are detected.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,181,949 B1
DATED : January 30, 2001
INVENTOR(S) : Ozluturk et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title page,
In the first column, next to section "(75) Inventors:" and next to the second named inventor, "Gary R. Lomp", delete "Cenerport" and insert therefor -- Centerport -- .

In the first column, below section "(22) Filed: January 6, 1998", insert therefor --

Item [63] -- Related U.S. Application Data - Continuation of Application No. 08/670,162, June 27, 1996, now U.S. Patent No. 5,841,768. --

Signed and Sealed this

Eleventh Day of September, 2001

Attest:

Nicholas P. Godici

NICHOLAS P. GODICI

Attesting Officer *Acting Director of the United States Patent and Trademark Office*

Exhibit C

US005841768A

United States Patent [19]

Ozluturk et al.

[11] **Patent Number:** **5,841,768**

[45] **Date of Patent:** **Nov. 24, 1998**

[54] **METHOD OF CONTROLLING INITIAL POWER RAMP-UP IN CDMA SYSTEMS BY USING SHORT CODES**

[75] Inventors: **Faith M. Ozluturk**, Port Washington; **Gary R. Lomp**, Cenerport, both of N.Y.

[73] Assignee: **InterDigital Technology Corporation**, Wilmington, Del.

[21] Appl. No.: **670,162**

[22] Filed: **Jun. 27, 1996**

[51] **Int. Cl.**^{6} **H04B 7/005**; H04B 7/216

[52] **U.S. Cl.** **370/335**; 375/200

[58] **Field of Search** 370/252, 320, 370/335, 342, 332, 331, 318; 375/200, 206; 455/69, 70, 517

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Primary Examiner—Chau Nguyen
Attorney, Agent, or Firm—Volpe and Koenig, P.C.

[57] **ABSTRACT**

A system and method of controlling transmission power during the establishment of a channel in a CDMA communication system utilize the transmission of a short code from a subscriber unit to a base station during initial power ramp-up. The short code is a sequence for detection by the base station which has a much shorter period than a conventional spreading code. The ramp-up starts from a power level that is guaranteed to be lower than the required power level for detection by the base station. The subscriber unit quickly increases transmission power while repeatedly transmitting the short code until the signal is detected by the base station. Once the base station detects the short code, it sends an indication to the subscriber unit to cease increasing transmission power. The use of short codes limits power overshoot and interference to other subscriber stations and permits the base station to quickly synchronize to the spreading code used by the subscriber unit.

21 Claims, 11 Drawing Sheets

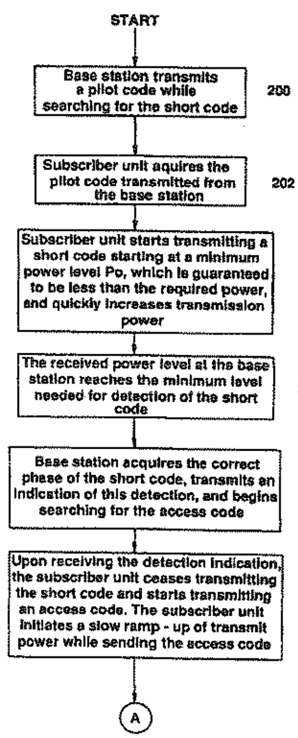


FIG.1

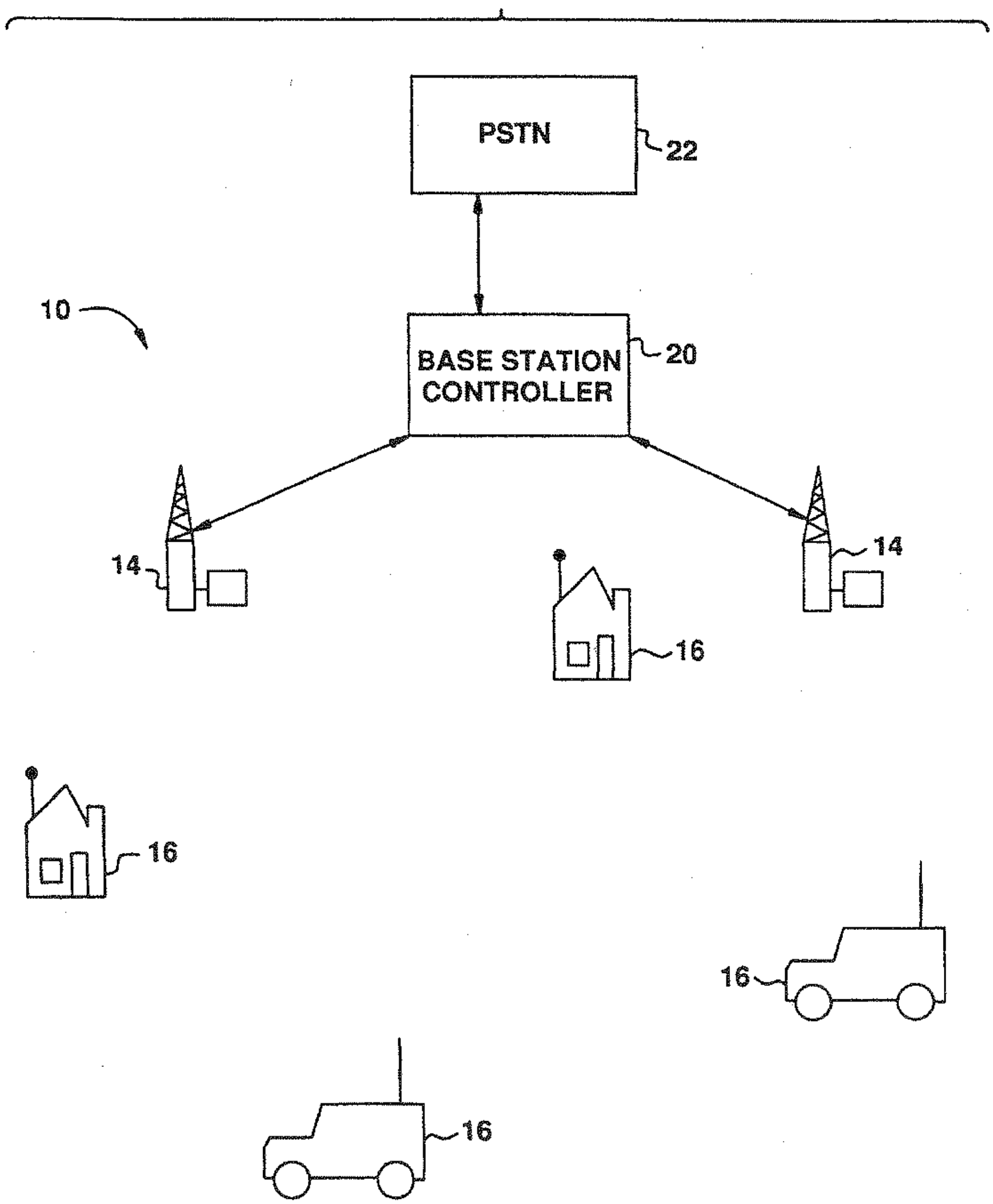


FIG.2

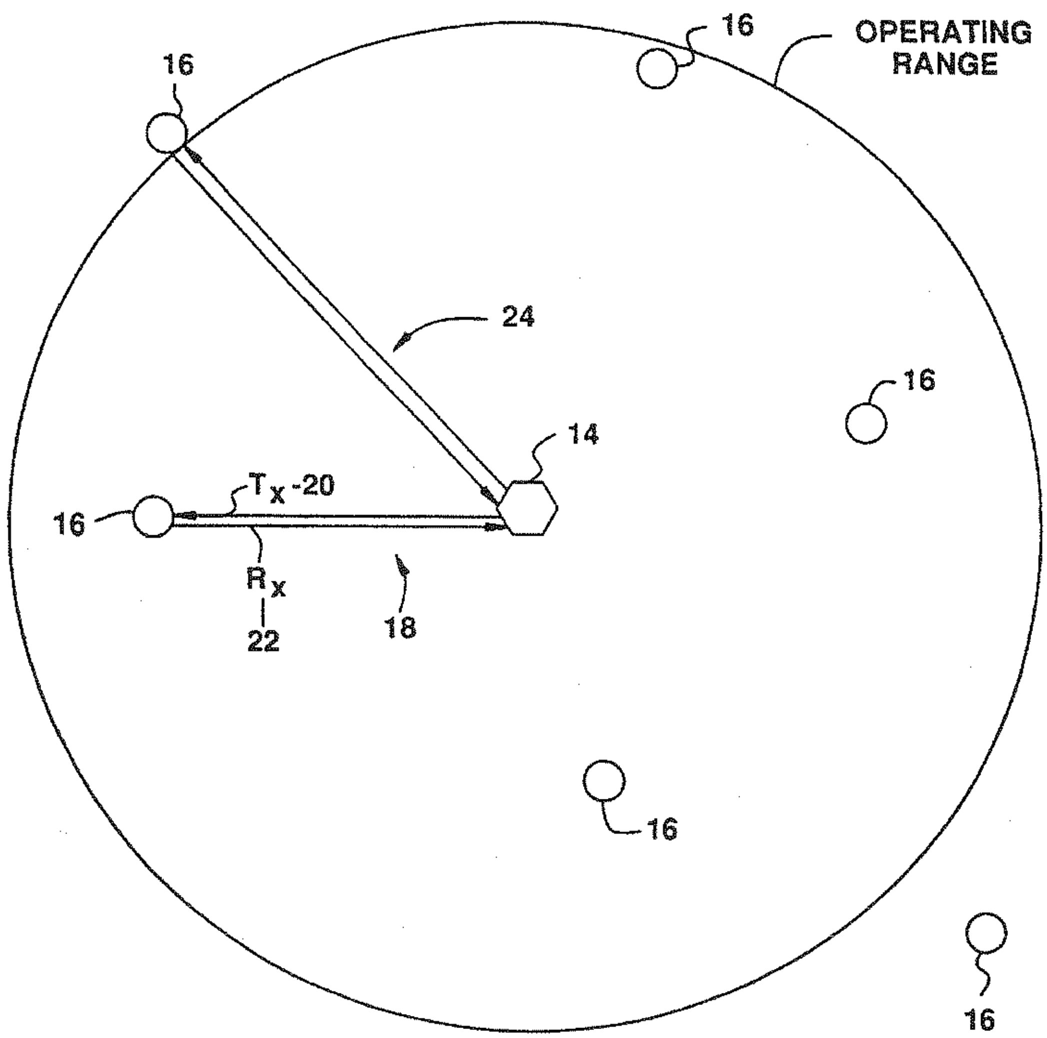


FIG.3

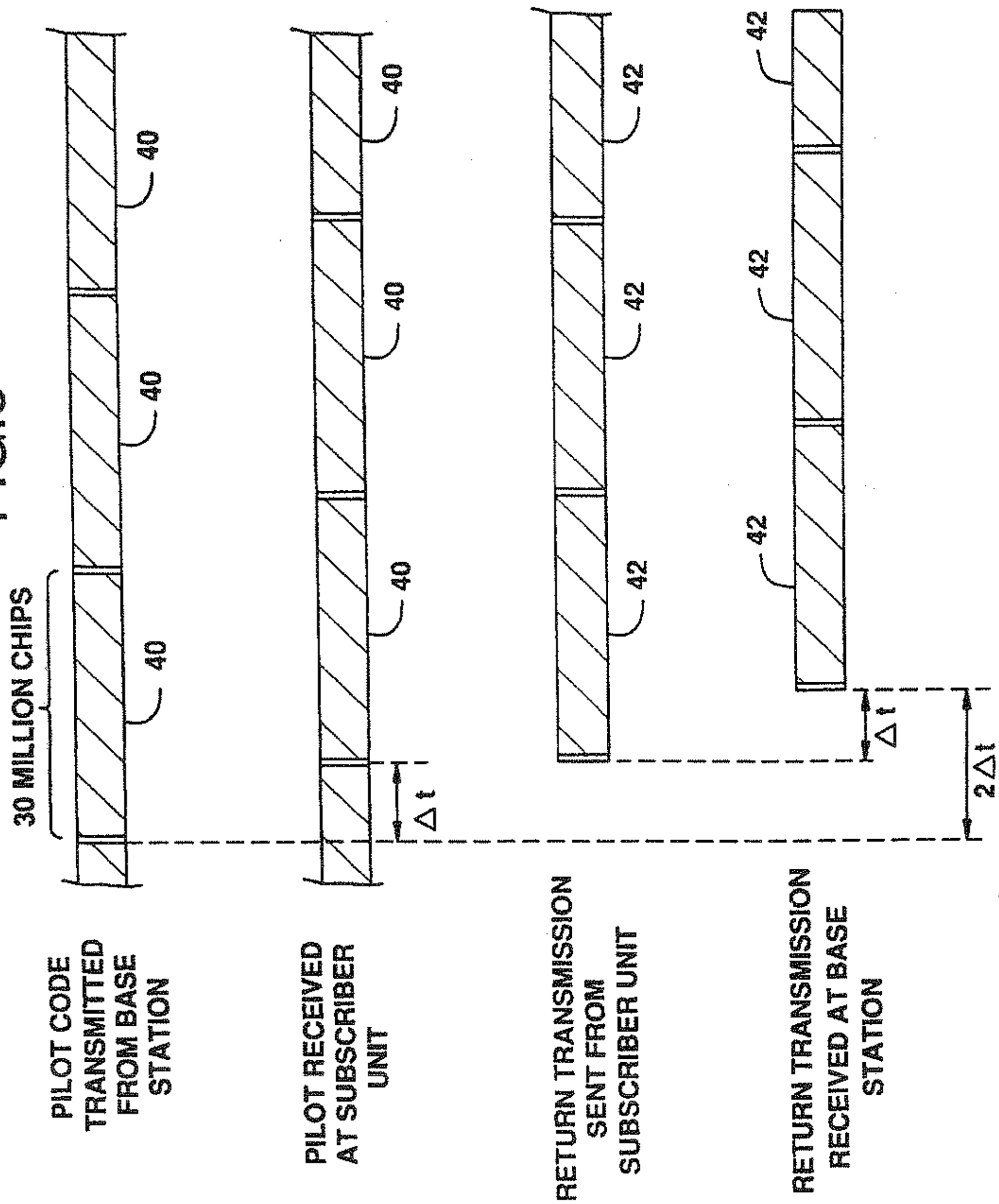

30 MILLION CHIPS
40
40
40
40
40
40
40
Δt
42
42
42
42
42
42
Δt
2Δt
PILOT CODE TRANSMITTED FROM BASE STATION
PILOT RECEIVED AT SUBSCRIBER UNIT
RETURN TRANSMISSION SENT FROM SUBSCRIBER UNIT
RETURN TRANSMISSION RECEIVED AT BASE STATION

FIG.4

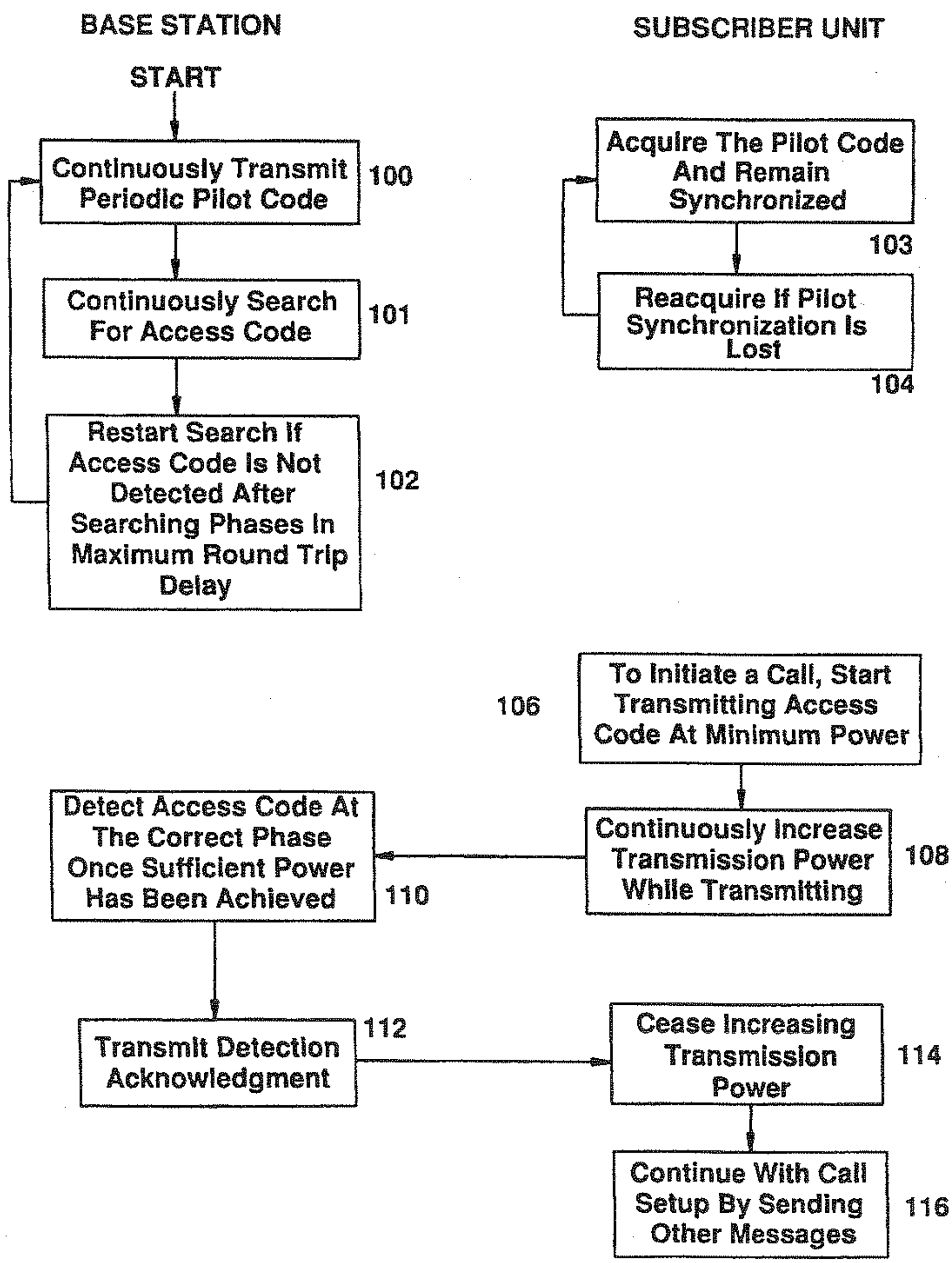

BASE STATION
SUBSCRIBER UNIT
START
Continuously Transmit Periodic Pilot Code
100
Continuously Search For Access Code
101
Restart Search If Access Code Is Not Detected After Searching Phases In Maximum Round Trip Delay
102
Acquire The Pilot Code And Remain Synchronized
103
Reacquire If Pilot Synchronization Is Lost
104
106
To Initiate a Call, Start Transmitting Access Code At Minimum Power
Detect Access Code At The Correct Phase Once Sufficient Power Has Been Achieved
110
Continuously Increase Transmission Power While Transmitting
108
Transmit Detection Acknowledgment
112
Cease Increasing Transmission Power
114
Continue With Call Setup By Sending Other Messages
116

FIG.5

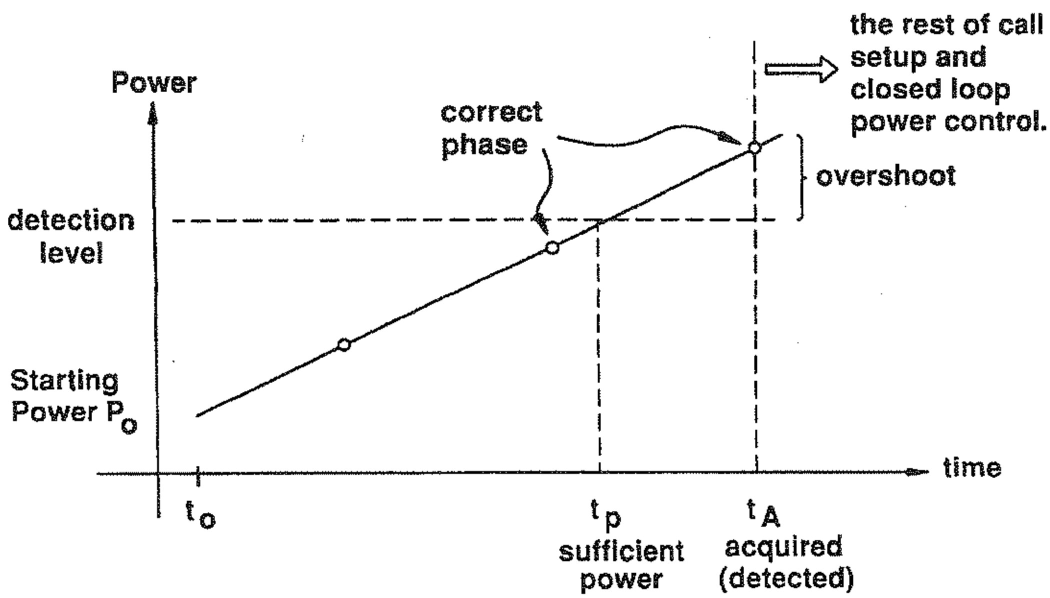

Power
correct
phase
the rest of call
setup and
closed loop
power control.
overshoot
detection
level
Starting
Power P_o
time
t_o
t_p
sufficient
power
t_A
acquired
(detected)

FIG.7

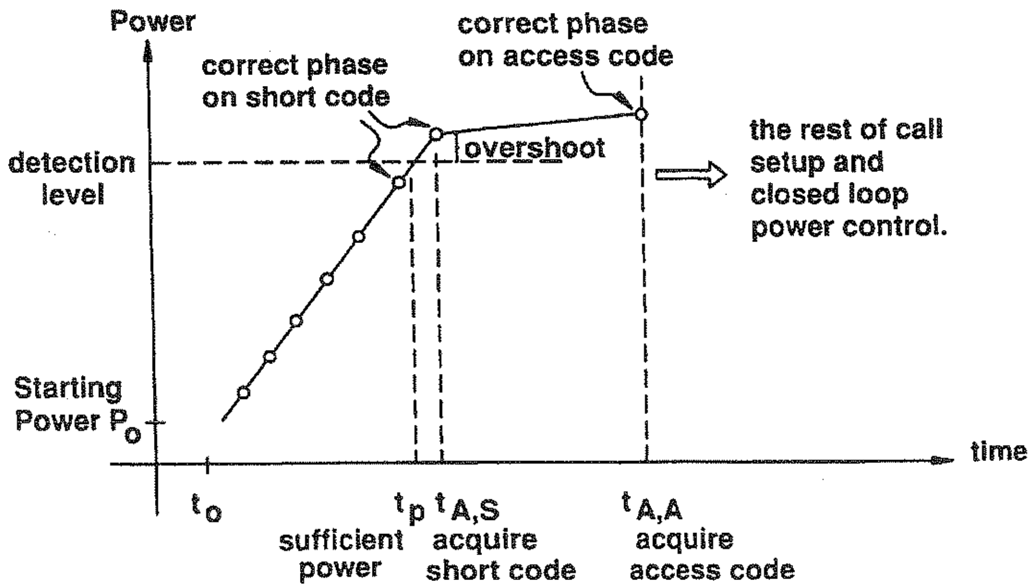

Power
correct phase
on short code
correct phase
on access code
overshoot
detection
level
the rest of call
setup and
closed loop
power control.
Starting
Power P_o
time
t_o
t_p
sufficient
power
$t_{A,S}$
acquire
short code
$t_{A,A}$
acquire
access code

FIG.6A

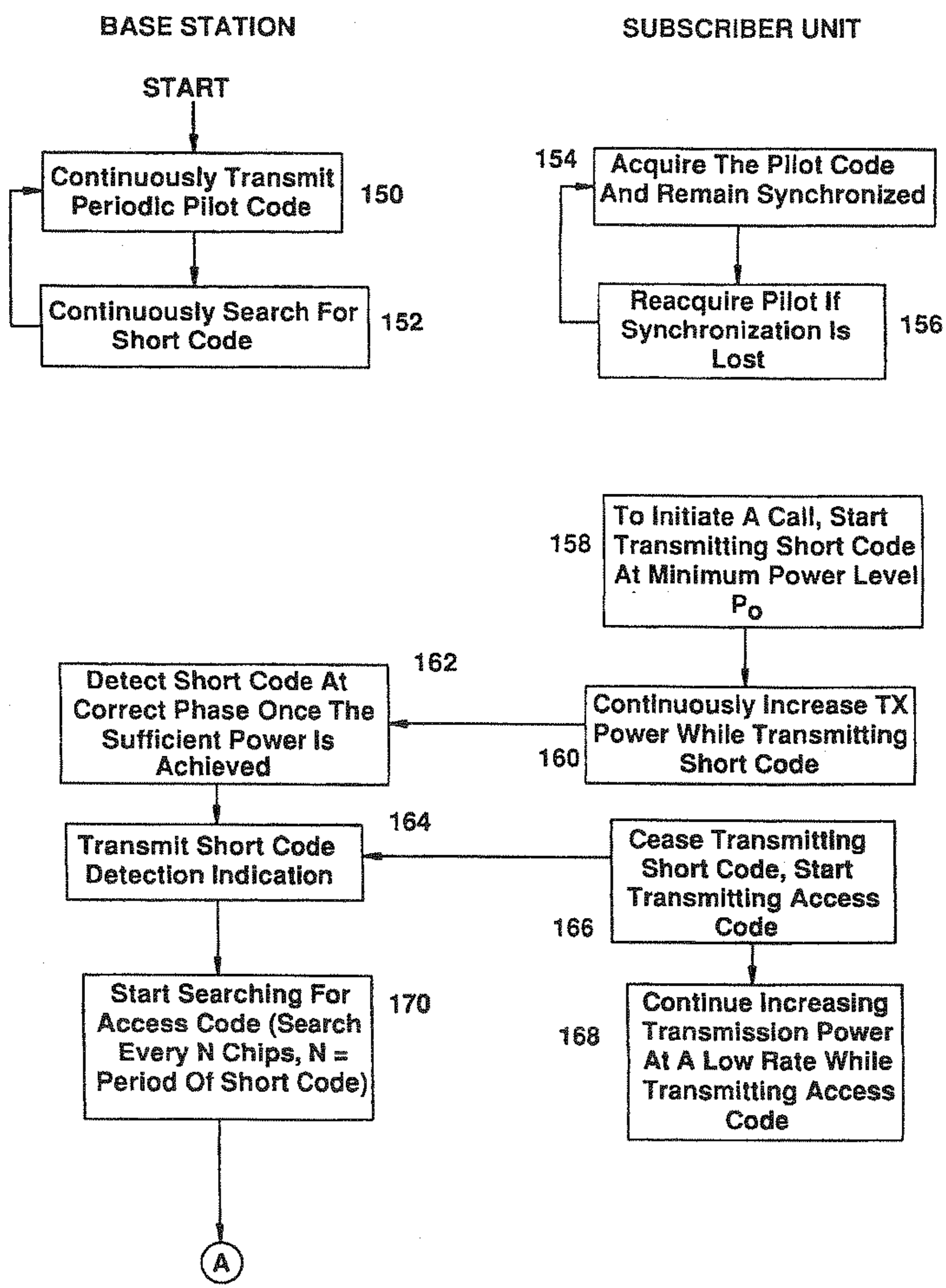

BASE STATION
SUBSCRIBER UNIT
START
Continuously Transmit Periodic Pilot Code
150
Continuously Search For Short Code
152
154
Acquire The Pilot Code And Remain Synchronized
Reacquire Pilot If Synchronization Is Lost
156
158
To Initiate A Call, Start Transmitting Short Code At Minimum Power Level Po
162
Detect Short Code At Correct Phase Once The Sufficient Power Is Achieved
Continuously Increase TX Power While Transmitting Short Code
160
164
Transmit Short Code Detection Indication
Cease Transmitting Short Code, Start Transmitting Access Code
166
Start Searching For Access Code (Search Every N Chips, N = Period Of Short Code)
170
168
Continue Increasing Transmission Power At A Low Rate While Transmitting Access Code
A

FIG.6B

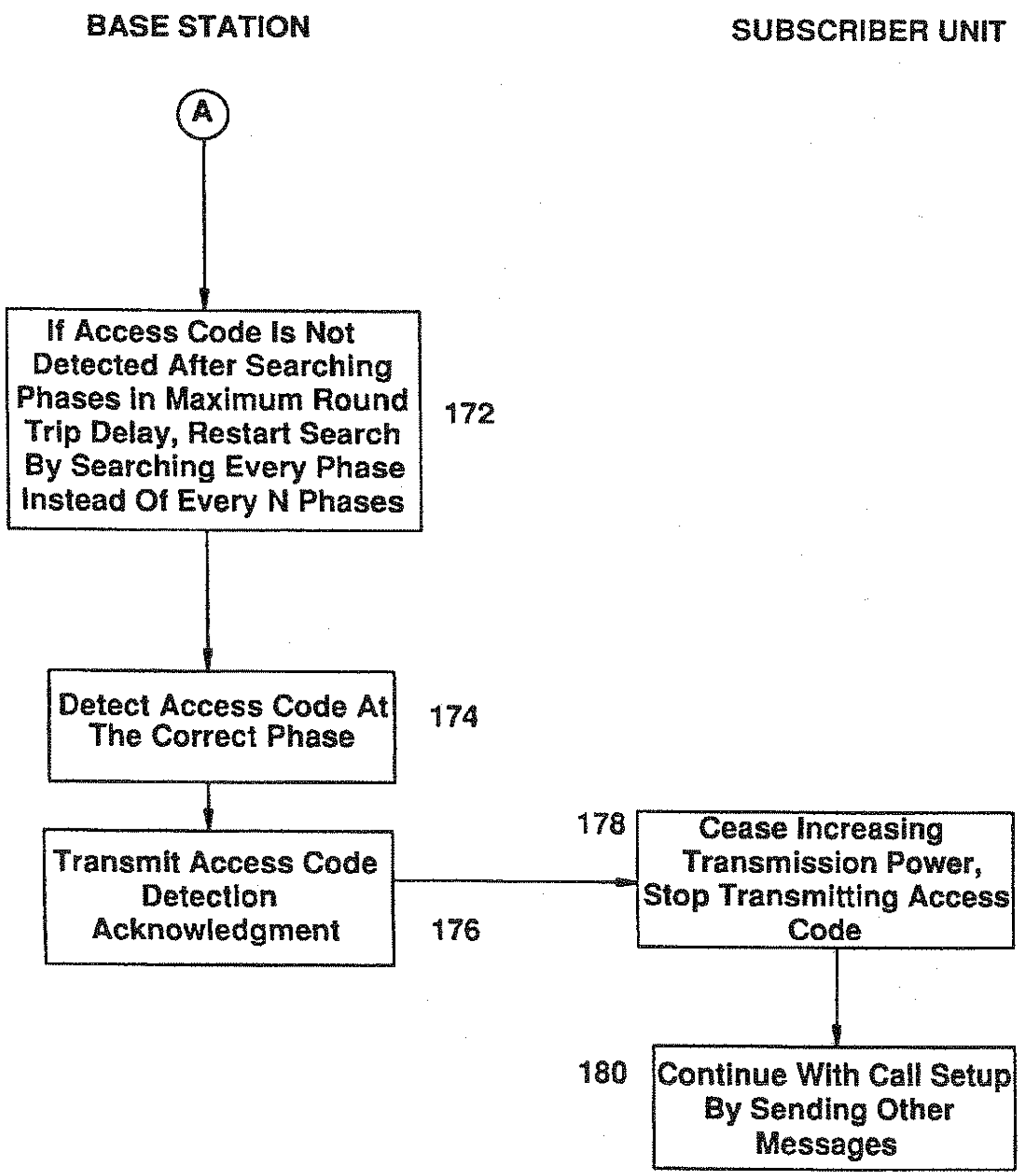

BASE STATION
SUBSCRIBER UNIT
A
If Access Code Is Not Detected After Searching Phases In Maximum Round Trip Delay, Restart Search By Searching Every Phase Instead Of Every N Phases
172
Detect Access Code At The Correct Phase
174
Transmit Access Code Detection Acknowledgment
176
178
Cease Increasing Transmission Power, Stop Transmitting Access Code
180
Continue With Call Setup By Sending Other Messages

FIG.8

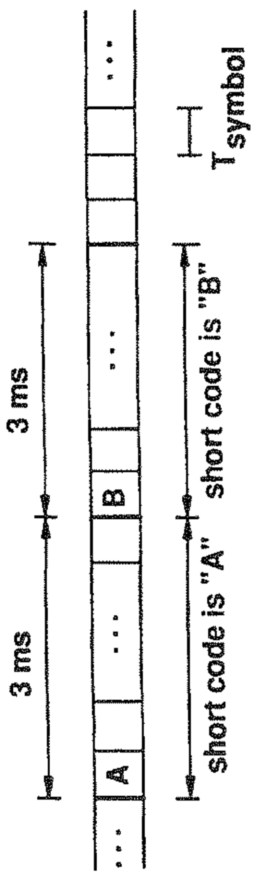

3 ms
3 ms
A
B
short code is "A"
short code is "B"
T symbol

FIG.9

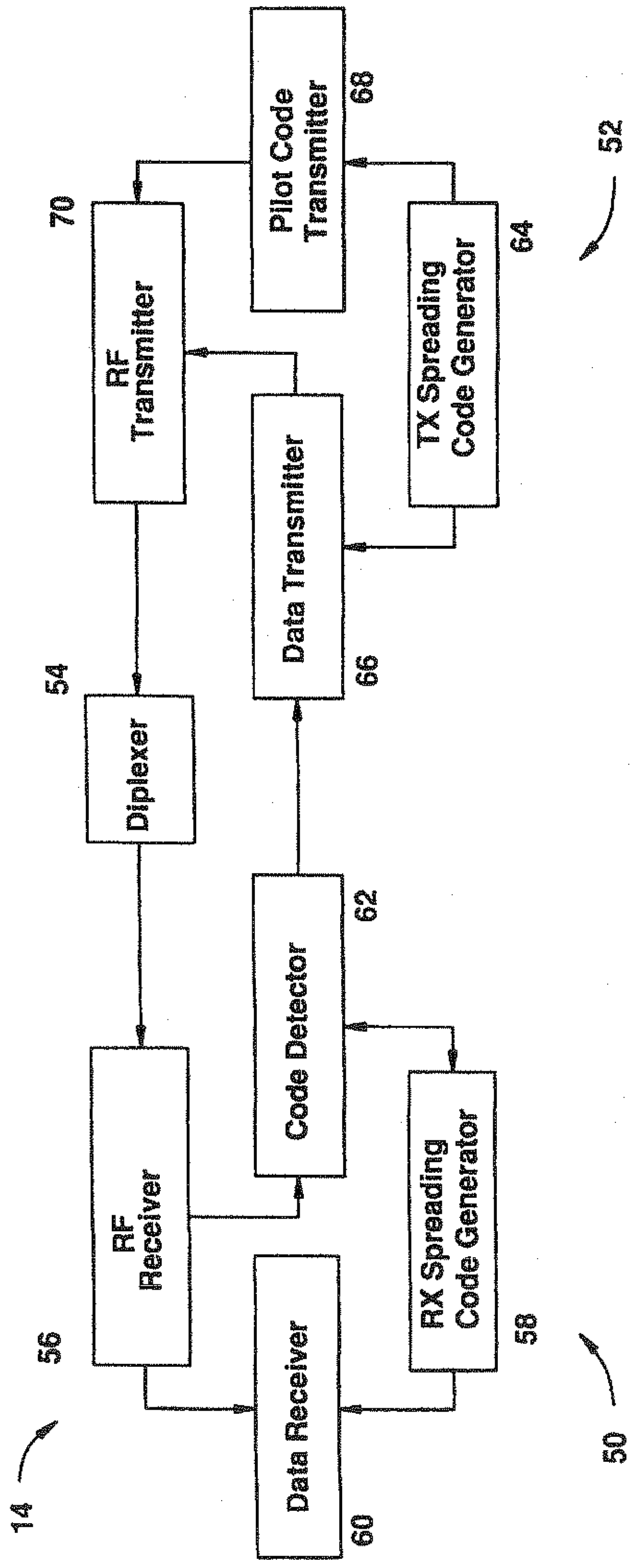

Pilot Code Transmitter
68
70
RF Transmitter
Data Transmitter
TX Spreading Code Generator
64
52
54
Diplexer
66
Code Detector
62
RF Receiver
56
Data Receiver
60
RX Spreading Code Generator
58
14
50

FIG. 10

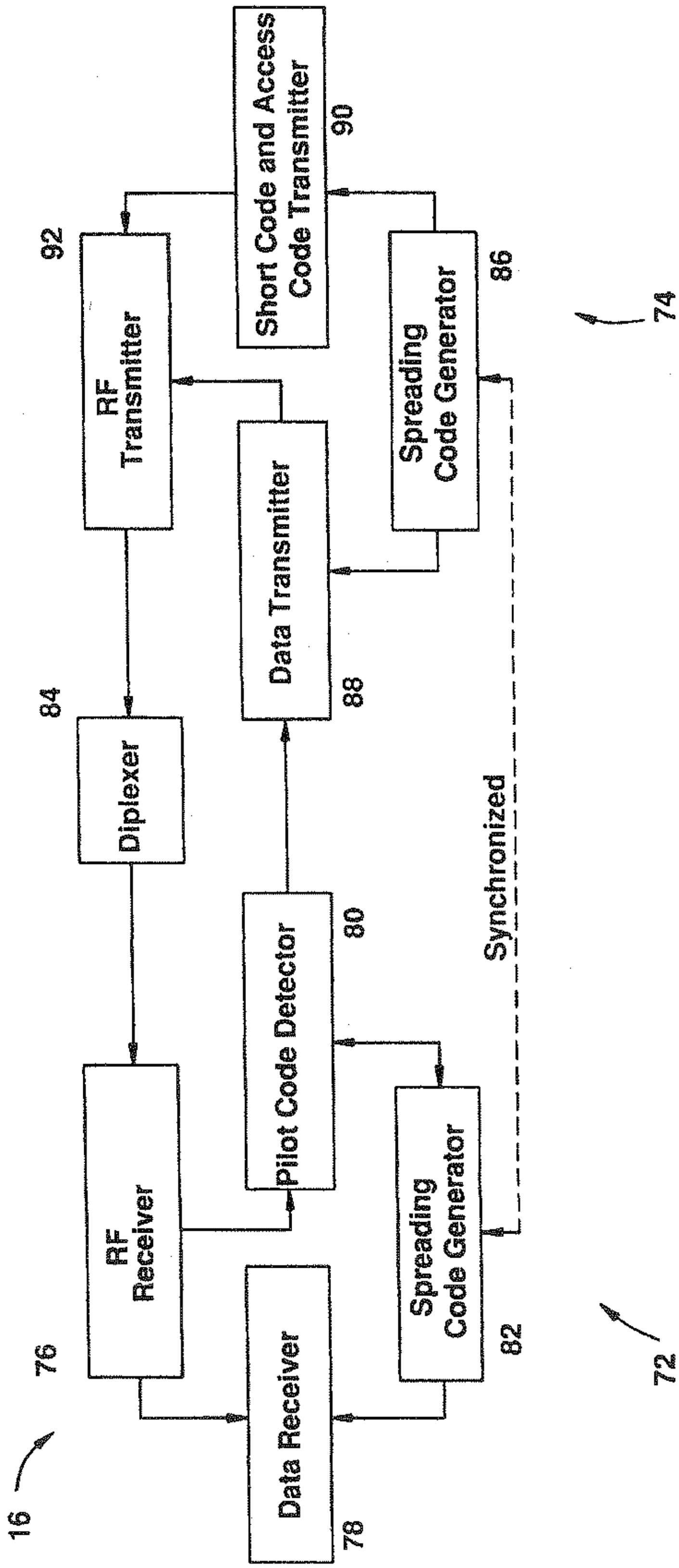

Short Code and Access Code Transmitter
90
92
RF Transmitter
Spreading Code Generator
86
74
Data Transmitter
88
84
Diplexer
Synchronized
Pilot Code Detector
80
RF Receiver
Spreading Code Generator
82
72
76
Data Receiver
78
16

FIG.11A

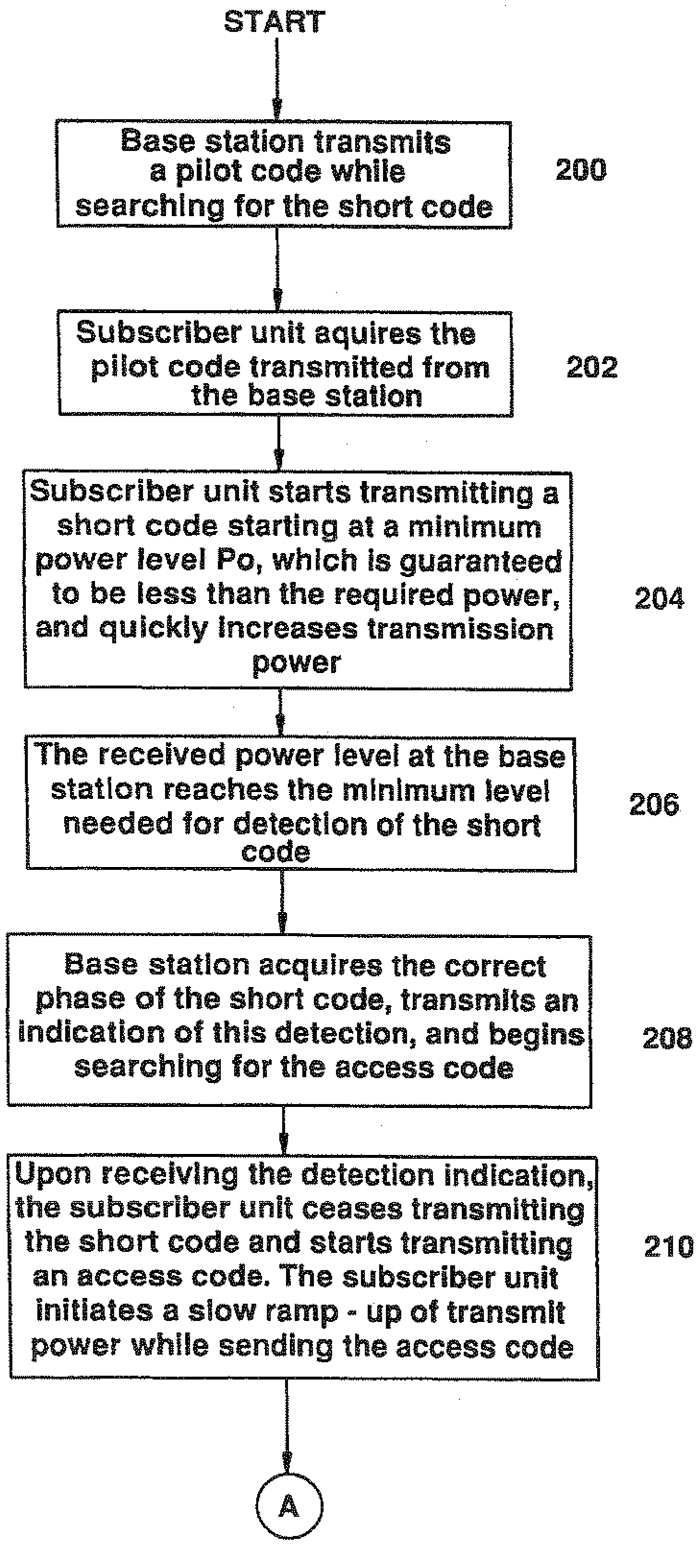
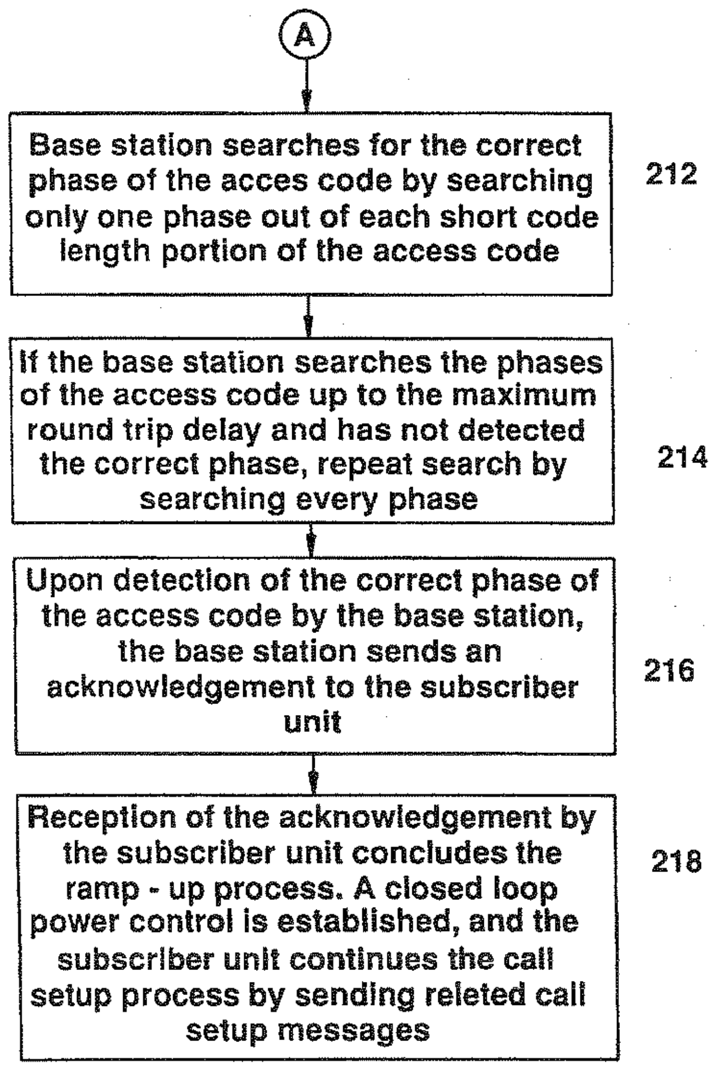

START
Base station transmits a pilot code while searching for the short code
200
Subscriber unit aquires the pilot code transmitted from the base station
202
Subscriber unit starts transmitting a short code starting at a minimum power level Po, which is guaranteed to be less than the required power, and quickly increases transmission power
204
The received power level at the base station reaches the minimum level needed for detection of the short code
206
Base station acquires the correct phase of the short code, transmits an indication of this detection, and begins searching for the access code
208
Upon receiving the detection indication, the subscriber unit ceases transmitting the short code and starts transmitting an access code. The subscriber unit initiates a slow ramp - up of transmit power while sending the access code
210
A

FIG.11B


A
Base station searches for the correct phase of the acces code by searching only one phase out of each short code length portion of the access code
212
If the base station searches the phases of the access code up to the maximum round trip delay and has not detected the correct phase, repeat search by searching every phase
214
Upon detection of the correct phase of the access code by the base station, the base station sends an acknowledgement to the subscriber unit
216
Reception of the acknowledgement by the subscriber unit concludes the ramp - up process. A closed loop power control is established, and the subscriber unit continues the call setup process by sending releted call setup messages
218

METHOD OF CONTROLLING INITIAL POWER RAMP-UP IN CDMA SYSTEMS BY USING SHORT CODES

CROSS REFERENCE TO RELATED APPLICATION

This application is being filed concurrently with an application U.S. Ser. No. 08/669,775 entitled Code Division Multiple Access (CDMA) System and which is herein incorporated by reference as if fully set forth.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to CDMA communication systems. More specifically, the present invention relates to a CDMA communication system which utilizes the transmission of short codes from subscriber units to a base station to reduce the time required for the base station to detect the signal from a subscriber unit. The improved detection time allows a faster ramp-up of the initial transmit power from the subscriber units while reducing the unnecessary power overshoot.

2. Description of Related Art

The use of wireless telecommunication systems has grown dramatically in the last decade as the reliability and capacity of the systems have improved. Wireless communication systems are being utilized in a variety of applications where land line based systems are impractical or impossible to use. Applications of wireless communications include cellular phone communications, communications in remote locations, and temporary communications for disaster recovery. Wireless communication systems have also become an economically viable alternative to replacing aging telephone lines and outdated telephone equipment.

The portion of the RF spectrum available for use by wireless communication systems is a critical resource. The RF spectrum must be shared among all commercial, governmental and military applications. There is a constant desire to improve the efficiency of wireless communication systems in order to increase system capacity.

Code division multiple access (CDMA) wireless communication systems have shown particular promise in this area. Although more traditional time division multiple access (TDMA) and frequency division multiple access (FDMA) systems have improved using the latest technological advances, CDMA systems, in particular Broadband Code Division Multiple Access™ (B-CDMA™) systems, have significant advantages over TDMA and FDMA systems. This efficiency is due to the improved coding and modulation density, interference rejection and multipath tolerance of B-CDMA™ systems, as well as reuse of the same spectrum in every communication cell. The format of CDMA communication signals also makes it extremely difficult to intercept calls, thereby ensuring greater privacy for callers and providing greater immunity against fraud.

In a CDMA system, the same portion of the frequency spectrum is used for communication by all subscriber units. Each subscriber unit's baseband data signal is multiplied by a code sequence, called the "spreading code", which has a much higher rate than the data. The ratio of the spreading code rate to the data symbol rate is called the "spreading factor" or the "processing gain". This coding results in a much wider transmission spectrum than the spectrum of the baseband data signal, hence the technique is called "spread spectrum". Subscriber units and their communications can

be discriminated by assigning a unique spreading code to each communication link which is called a CDMA channel. Since all communications are sent over the same frequency band, each CDMA communication overlaps communications from other subscriber units and noise-related signals in both frequency and time.

The use of the same frequency spectrum by a plurality of subscriber units increases the efficiency of the system. However, it also causes a gradual degradation of the performance of the system as the number of users increase. Each subscriber unit detects communication signals with its unique spreading code as valid signals and all other signals are viewed as noise. The stronger the signal from a subscriber unit arrives at the base station, the more interference the base station experiences when receiving and demodulating signals from other subscriber units. Ultimately, the power from one subscriber unit may be great enough to terminate communications of other subscriber units. Accordingly, it is extremely important in wireless CDMA communication systems to control the transmission power of all subscriber units. This is best accomplished by using a closed loop power control algorithm once a communication link is established. A detailed explanation of such a closed loop algorithm is disclosed in U.S. Patent Application entitled Code Division Multiple Access (CDMA) System and Method filed concurrently herewith, which is incorporated by reference as if fully set forth.

The control of transmission power is particularly critical when a subscriber unit is attempting to initiate communications with a base station and a power control loop has not yet been established. Typically, the transmission power required from a subscriber unit changes continuously as a function of the propagation loss, interference from other subscribers, channel noise, fading and other channel characteristics. Therefore, a subscriber unit does not know the power level at which it should start transmitting. If the subscriber unit begins transmitting at a power level that is too high, it may interfere with the communications of other subscriber units and may even terminate the communications of other subscriber units. If the initial transmission power level is too low, the subscriber unit will not be detected by the base station and a communication link will not be established.

There are many methods for controlling transmission power in a CDMA communication system. For example, U.S. Pat. No. 5,056,109 (Gilhousen et al.) discloses a transmission power control system wherein the transmission power of the subscriber unit is based upon periodic signal measurements from both the subscriber unit and the base station. The base station transmits a pilot signal to all subscriber units which analyze the received pilot signal, estimate the power loss in the transmitted signal and adjust their transmission power accordingly. Each subscriber unit includes a non-linear loss output filter which prevents sudden increases in power which would cause interference to other subscriber units. This method is too complex to permit a base station to quickly acquire a subscriber unit while limiting the interference to other subscriber units. In addition, the propagation losses, interference and noise levels experienced in a forward link (transmission from the base station to a subscriber unit) is often not the same as in a reverse link (transmission from a subscriber unit to the base station). Reverse link power estimates based on forward link losses are not precise.

Many other types of prior art transmission power control systems require complex control signaling between communicating units or preselected transmission values to control transmission power. These power control techniques are inflexible and often impractical to implement.

Accordingly, there is a need for an efficient method of controlling the initial ramp-up of transmission power by subscriber units in a wireless CDMA communication system.

SUMMARY OF THE INVENTION

The present invention comprises a novel method of controlling transmission power during the establishment of a channel in a CDMA communication system by utilizing the transmission of a short code from a subscriber unit to a base station during initial power ramp-up. The short code is a sequence for detection by the base station which has a much shorter period than a conventional spreading code. The ramp-up starts from a power level that is guaranteed to be lower than the required power level for detection by the base station. The subscriber unit quickly increases transmission power while repeatedly transmitting the short code until the signal is detected by the base station. Once the base station detects the short code, it sends an indication to the subscriber unit to cease increasing transmission power. The use of short codes limits power overshoot and interference to other subscriber stations and permits the base station to quickly synchronize to the spreading code used by the subscriber unit.

Accordingly, it is an object of the present invention to provide an improved technique for controlling power ramp-up during establishment of a communication channel between a CDMA subscriber unit and base station.

Other objects and advantages of the present invention will become apparent after reading the description of a presently preferred embodiment.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic overview of a code division multiple access communication system in accordance with the present invention;

FIG. 2 is a diagram showing the operating range of a base station;

FIG. 3 is a timing diagram of communication signals between a base station and a subscriber unit;

FIG. 4 is a flow diagram of the establishment of a communication channel between a base station and a subscriber unit;

FIG. 5 is a graph of the transmission power output from a subscriber unit;

FIGS. 6A and 6B are flow diagrams of the establishment of a communication channel between a base station and a subscriber unit in accordance with the preferred embodiment of the present invention using short codes;

FIG. 7 is a graph of the transmission power output from a subscriber unit using short codes;

FIG. 8 shows the adaptive selection of short codes;

FIG. 9 is a block diagram of a base station in accordance with the present invention;

FIG. 10 is a block diagram of the subscriber unit in accordance with the present invention; and

FIGS. 11A and 11B are flow diagrams of the ramp-up procedure implemented in accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The preferred embodiment will be described with reference to the drawing figures where identical numerals represent similar elements throughout.

A communication network **10** embodying the present invention is shown in FIG. **1**. The communication network **10** generally comprises one or more base stations **14**, each of which is in wireless communication with a plurality of subscriber units **16**, which may be fixed or mobile. Each subscriber unit **16** communicates with either the closest base station **14** or the base station **14** which provides the strongest communication signal. The base stations **14** also communicate with a base station controller **20**, which coordinates communications among base stations **14**. The communication network **10** may also be connected to a public switched telephone network (PSTN) **22**, wherein the base station controller **20** also coordinates communications between the base stations **14** and the PSTN **22**. Preferably, each base station **14** communicates with the base station controller **20** over a wireless link, although a land line may also be provided. A land line is particularly applicable when a base station **14** is in close proximity to the base station controller **20**.

The base station controller **20** performs several functions. Primarily, the base station controller **20** provides all of the operations, administrative and maintenance (OA&M) signaling associated with establishing and maintaining all of the wireless communications between the subscriber units **16**, the base stations **14**, and the base station controller **20**. The base station controller **20** also provides an interface between the wireless communication system **10** and the PSTN **22**. This interface includes multiplexing and demultiplexing of the communication signals that enter and leave the system **10** via the base station controller **20**. Although the wireless communication system **10** is shown employing antennas to transmit RF signals, one skilled in the art should recognize that communications may be accomplished via microwave or satellite uplinks. Additionally, the functions of the base station controller **20** may be combined with a base station **14** to form a "master base station".

Referring to FIG. **2**, the propagation of signals between a base station **14** and a plurality of subscriber units **16** is shown. A two-way communication channel (link) **18** comprises a signal transmitted **20** (Tx) from the base station **14** to the subscriber unit **16** and a signal received **22** (Rx) by the base station **14** from the subscriber unit **16**. The Tx signal **20** is transmitted from the base station **14** and is received by the subscriber unit **16** after a propagation delay Δt. Similarly, the Rx signal originates at the subscriber unit **16** and terminates at the base station **14** after a further propagation delay At. Accordingly, the round trip propagation delay is $2\Delta t$. In the preferred embodiment, the base station **14** has an operating range of approximately 30 kilometers. The round trip propagation delay **24** associated with a subscriber unit **16** at the maximum operating range is 200 microseconds.

It should be apparent to those of skill in the art that the establishment of a communication channel between a base station and a subscriber unit is a complex procedure involving many tasks performed by the base station and the subscriber unit which are outside the scope of the present invention. The present invention is directed to initial power ramp-up and synchronization during the establishment of a communication channel.

Referring to FIG. **3**, the signaling between a base station **14** and a subscriber unit **16** is shown. In accordance with the present invention, the base station **14** continuously transmits a pilot code **40** to all of the subscriber units **16** located within the transmitting range of the base station **14**. The pilot code **40** is a spreading code which carries no data bits. The pilot code **40** is used for subscriber unit **16** acquisition and synchronization, as well as for determining the parameters of the adaptive matched filter used in the receiver.

The subscriber unit 16 must acquire the pilot code 40 transmitted by the base station 14 before it can receive or transmit any data. Acquisition is the process whereby the subscriber unit 16 aligns its locally generated spreading code with the received pilot code 40. The subscriber unit 16 searches through all of the possible phases of the received pilot code 40 until it detects the correct phase, (the beginning of the pilot code 40).

The subscriber unit 16 then synchronizes its transmit spreading code to the received pilot code 40 by aligning the beginning of its transmit spreading code to the beginning of the pilot code 40. One implication of this receive and transmit synchronization is that the subscriber unit 16 introduces no additional delay as far as the phase of the spreading codes are concerned. Accordingly, as shown in FIG. 3, the relative delay between the pilot code 40 transmitted from the base station 14 and the subscriber unit's transmit spreading code 42 received at the base station 14 is $2\Delta t$, which is solely due to the round trip propagation delay.

In the preferred embodiment, the pilot code is 29,877,120 chips in length and takes approximately 2 to 5 seconds to transmit, depending on the spreading factor. The length of the pilot code 40 was chosen to be a multiple of the data symbol no matter what kind of data rate or bandwidth is used. As is well known by those of skill in the art, a longer pilot code 40 has better randomness properties and the frequency response of the pilot code 40 is more uniform. Additionally, a longer pilot code 40 provides low channel cross correlation, thus increasing the capacity of the system 10 to support more subscriber units 16 with less interference. The use of a long pilot code 40 also supports a greater number of random short codes. For synchronization purposes, the pilot code 40 is chosen to have the same period as all of the other spreading codes used by the system 10. Thus, once a subscriber unit 16 acquires the pilot code 40, it is synchronized to all other signals transmitted from the base station 14.

During idle periods, when a call is not in progress or pending, the subscriber unit 16 remains synchronized to the base station 14 by periodically reacquiring the pilot code 40. This is necessary for the subscriber unit 16 to receive and demodulate any downlink transmissions, in particular paging messages which indicate incoming calls.

When a communication link is desired, the base station 14 must acquire the signal transmitted from the subscriber unit 16 before it can demodulate the data. The subscriber unit 16 must transmit an uplink signal for acquisition by the base station 14 to begin establishing the two-way communication link. A critical parameter in this procedure is the transmission power level of the subscriber unit 16. A transmission power level that is too high can impair communications in the whole service area, whereas a transmission power level that is too low can prevent the base station 14 from detecting the uplink signal.

In a first embodiment of the present invention the subscriber unit 16 starts transmitting at a power level guaranteed to be lower than what is required and increases transmission power output until the correct power level is achieved. This avoids sudden introduction of a strong interference, hence improving system 10 capacity.

The establishment of a communication channel in accordance with the present invention and the tasks performed by the base station 14 and a subscriber unit 16 are shown in FIG. 4. Although many subscriber units 16 may be located within the operating range of the base station 14, reference will be made hereinafter to a single subscriber unit 16 for simplicity in explaining the operation of the present invention.

The base station 14 begins by continuously transmitting a periodic pilot code 40 to all subscriber units 16 located within the operating range of the base station 14 (step 100). As the base station 14 transmits the pilot code 40 (step 100), the base station 14 searches (step 101) for an "access code" 42 transmitted by a subscriber unit 16. The access code 42 is a known spreading code transmitted from a subscriber unit 16 to the base station 14 during initiation of communications and power ramp-up. The base station 14 must search through all possible phases (time shifts) of the access code 42 transmitted from the subscriber unit 16 in order to find the correct phase. This is called the "acquisition" or the "detection" process (step 101). The longer the access code 42, the longer it takes for the base station 14 to search through the phases and acquire the correct phase.

As previously explained, the relative delay between signals transmitted from the base station 14 and return signals received at the base station 14 corresponds to the round trip propagation delay $2\Delta t$. The maximum delay occurs at the maximum operating range of the base station 14, known as the cell boundary. Accordingly, the base station 14 must search up to as many code phases as there are in the maximum round trip propagation delay, which is typically less code phases than there are in a code period.

For a data rate Rb and spreading code rate Rc, the ratio L=Rc/Rb is called the spreading factor or the processing gain. In the preferred embodiment of the present invention, the cell boundary radius is 30 km, which corresponds to approximately between 1000 and 2500 code phases in the maximum round trip delay, depending on the processing gain.

If the base station 14 has not detected the access code after searching through the code phases corresponding to the maximum round trip delay the search is repeated starting from the phase of the pilot code 40 which corresponds to zero delay (step 102).

During idle periods, the pilot code 40 from the base station 14 is received at the subscriber unit 16 which periodically synchronizes its transmit spreading code generator thereto (step 103). If synchronization with the pilot code 40 is lost, the subscriber unit 16 reacquires the pilot code 40 and resynchronizes (step 104).

When it is desired to initiate a communication link, the subscriber unit 16 starts transmitting the access code 42 back to the base station 14 (step 106). The subscriber unit 16 continuously increases the transmission power while retransmitting the access code 42 (step 108) until it receives an acknowledgment from the base station 14. The base station 14 detects the access code 42 at the correct phase once the minimum power level for reception has been achieved (step 110). The base station 14 subsequently transmits an access code detection acknowledgment signal (step 112) to the subscriber unit 16. Upon receiving the acknowledgment, the subscriber unit ceases the transmission power increase (step 114). With the power ramp-up completed, closed loop power control and call setup signaling is performed (step 116) to establish the two-way communication link.

Although this embodiment limits subscriber unit 16 transmission power, acquisition of the subscriber unit 16 by the base station 14 in this manner may lead to unnecessary power overshoot from the subscriber unit 16, thereby reducing the performance of the system 10.

The transmission power output profile of the subscriber unit 16 is shown in FIG. 5. At to, the subscriber unit 16 starts transmitting at the starting transmission power level P_0,

which is a power level guaranteed to be less than the power level required for detection by the base station **14**. The subscriber unit **16** continually increases the transmission power level until it receives the detection indication from the base station **14**. For the base station **14** to properly detect the access code **42** from the subscriber unit **16** the access code **42** must: 1) be received at a sufficient power level; and 2) be detected at the proper phase. Accordingly, referring to FIG. **5**, although the access code **42** is at a sufficient power level for detection by the base station **14** at t_p, the base station **14** must continue searching for the correct phase of the access code **42** which occurs at t_A.

Since the subscriber unit **16** continues to increase the output transmission power level until it receives the detection indication from the base station **14**, the transmission power of the access code **42** exceeds the power level required for detection by the base station **14**. This causes unnecessary interference to all other subscriber units **16**. If the power overshoot is too large, the interference to other subscriber units **16** may be so severe as to terminate ongoing communications of other subscriber units **16**.

The rate that the subscriber unit **16** increases transmission power to avoid overshoot may be reduced, however, this results in a longer call setup time. Those of skill in the art would appreciate that adaptive ramp-up rates can also be used, yet these rates have shortcomings and will not appreciably eliminate power overshoot in all situations.

The preferred embodiment of the present invention utilizes "short codes" and a two-stage communication link establishment procedure to achieve fast power ramp-up without large power overshoots. The spreading code transmitted by the subscriber unit **16** is much shorter than the rest of the spreading codes (hence the term short code), so that the number of phases is limited and the base station **14** can quickly search through the code. The short code used for this purpose carries no data.

The tasks performed by the base station **14** and the subscriber unit **16** to establish a communication channel using short codes in accordance with the preferred embodiment of the present invention are shown in FIGS. **6A** and **6B**. During idle periods, the base station **14** periodically and continuously transmits the pilot code to all subscriber units **16** located within the operating range of the base station **14** (step **150**). The base station **14** also continuously searches for a short code transmitted by the subscriber unit **16** (step **152**). The subscriber unit **16** acquires the pilot code and synchronizes its transmit spreading code generator to the pilot code. The subscriber unit **16** also periodically checks to ensure it is synchronized. If synchronization is lost, the subscriber unit **16** reacquires the pilot signal transmitted by the base station (step **156**).

When a communication link is desired, the subscriber unit **16** starts transmitting a short code at the minimum power level P_0 (step **158**) and continuously increases the transmission power level while retransmitting the short code (step **160**) until it receives an acknowledgment from the base station **14** that the short code has been detected by the base station **14**.

The access code in the preferred embodiment, as previously described herein, is approximately 30 million chips in length. However, the short code is much smaller. The short code can be chosen to be any length that is sufficiently short to permit quick detection. There is an advantage in choosing a short code length such that it divides the access code period evenly. For the access code code described herein, the short code is preferably chosen to be 32, 64 or 128 chips in length. Alternatively, the short code may be as short as one symbol length, as will be described in detail hereinafter.

Since the start of the short code and the start of the access code are synchronized, once the base station **14** acquires the short code, the base station **14** knows that the corresponding phase of the access code is an integer multiple of N chips from the phase of the short code where N is the length of the short code. Accordingly, the base station **14** does not have to search all possible phases corresponding to the maximum round trip propagation delay.

Using the short code, the correct phase for detection by the base station **14** occurs much more frequently. When the minimum power level for reception has been achieved, the short code is quickly detected (step **162**) and the transmission power overshoot is limited. The transmission power ramp-up rate may be significantly increased without concern for a large power overshoot. In the preferred embodiment of the present invention, the power ramp-up rate using the short code is 1 dB per millisecond.

The base station **14** subsequently transmits a short code detection indication signal (step **164**) to the subscriber unit **16** which enters the second stage of the power ramp-up upon receiving this indication. In this stage, the subscriber unit **16** ceases transmitting the short code (step **166**) and starts continuously transmitting a periodic access code (step **166**). The subscriber unit **16** continues to ramp-up its transmission power while transmitting the access code, however the ramp-up rate is now much lower than the previous ramp-up rate used with the short code (step **168**). The ramp-up rate with the access code is preferably 0.05 dB per millisecond. The slow ramp-up avoids losing synchronization with the base station **14** due to small changes in channel propagation characteristics.

At this point, the base station **14** has detected the short code at the proper phase and power level (step **162**). The base station **14** must now synchronize to the access code which is the same length as all other spreading codes and much longer than the short code. Utilizing the short code, the base station **14** is able to detect the proper phase of the access code much more quickly. The base station **14** begins searching for the proper phase of the access code (step **170**). However, since the start of the access code is synchronized with the start of the short code, the base station **14** is only required to search every N chips; where N=the length of the short code. In summary, the base station **14** quickly acquires the access code of the proper phase and power level by: 1) detecting the short code; and 2) determining the proper phase of the access code by searching every N chips of the access code from the beginning of the short code.

If the proper phase of the access code has not been detected after searching the number of phases in the maximum round trip delay the base station **14** restarts the search for the access code by searching every chip instead of every N chips (step **172**). When the proper phase of the access code has been detected (step **174**) the base station **14** transmits an access code detection acknowledgment (step **176**) to the subscriber unit **16** which ceases the transmission power increase (step **178**) upon receiving this acknowledgment. With the power ramp-up completed, closed loop power control and call setup signaling is performed (step **180**) to establish the two-way communication link.

Referring to FIG. **7**, although the starting power level P_0 is the same as in the prior embodiment, the subscriber unit **16** may ramp-up the transmission power level at a much higher rate by using a short code. The short code is quickly detected after the transmission power level surpasses the

minimum detection level, thus minimizing the amount of transmission power overshoot.

Although the same short code may be reused by the subscriber unit 16, in the preferred embodiment of the present invention the short codes are dynamically selected and updated in accordance with the following procedure. Referring to FIG. 8, the period of the short code is equal to one symbol length and the start of each period is aligned with a symbol boundary. The short codes are generated from a regular length spreading code. A symbol length portion from the beginning of the spreading code is stored and used as the short code for the next 3 milliseconds. Every 3 milliseconds, a new symbol length portion of the spreading code replaces the old short code. Since the spreading code period is an integer multiple of 3 milliseconds, the same short codes are repeated once every period of the spreading code.

Periodic updating of the short code averages the interference created by the short code over the entire spectrum. A detailed description of the selection and updating of the short codes is outside the scope of this invention. However, such a detailed description is disclosed in the related application U.S. Patent Appln. entitled Code Division Multiple Access (CDMA) System and Method.

A block diagram of the base station 14 is shown in FIG. 9. Briefly described, the base station 14 comprises a receiver section 50, a transmitter section 52 and a diplexer 54. An RF receiver 56 receives and down-converts the RF signal received from the diplexer 54. The receive spreading code generator 58 outputs a spreading code to both the data receiver 60 and the code detector 62. In the data receiver 60, the spreading code is correlated with the baseband signal to extract the data signal which is forwarded for further processing. The received baseband signal is also forwarded to the code detector 62 which detects the access code or the short code from the subscriber unit 16 and adjusts the timing of the spreading code generator 58 to establish a communication channel 18.

In the transmitter section 52 of the base station 14, the transmit spreading code generator 64 outputs a spreading code to the data transmitter 66 and the pilot code transmitter 68. The pilot code transmitter 68 continuously transmits the periodic pilot code. The data transmitter 66 transmits the short code detect indication and access code detect acknowledgment after the code detector 62 has detected the short code or the access code respectively. The data transmitter also sends other message and data signals. The signals from the data transmitter 66 and the pilot code transmitter 68 are combined and up-converted by the RF transmitter 70 for transmission to the subscriber units 16.

A block diagram of the subscriber unit 16 is shown in FIG. 10. Briefly described, the subscriber unit 16 comprises a receiver section 72, a transmitter section 74 and a diplexer 84. An RF receiver 76 receives and down-converts the RF signal received from the diplexer 84. A pilot code detector 80 correlates the spreading code with the baseband signal to acquire the pilot code transmitted by the base station 16. In this manner, the pilot code detector 80 maintains synchronization with the pilot code. The receiver spreading code generator 82 generates and outputs a spreading code to the data receiver 78 and the pilot code detector 80. The data receiver 78 correlates the spreading code with the baseband signal to process the short code detect indication and the access code detect acknowledgment transmitted by the base station 16.

The transmitter section 74 comprises a spreading code generator 86 which generates and outputs spreading codes to a data transmitter 88 and a short code and access code transmitter 90. The short code and access code transmitter 90 transmits these codes at different stages of the power ramp-up procedure as hereinbefore described. The signals output by the data transmitter 88 and the short code and access code transmitter 90 are combined and up-converted by the RF transmitter 92 for transmission to the base station 14. The timing of the receiver spreading code generator 82 is adjusted by the pilot code detector 80 through the acquisition process. The receiver and transmitter spreading code generators 82, 86 are also synchronized.

An overview of the ramp-up procedure in accordance with the preferred current invention is summarized in FIGS. 11A and 11B. The base station 14 transmits a pilot code while searching for the short code (step 200). The subscriber unit 16 acquires the pilot code transmitted from the base station 14 (step 202), starts transmitting a short code starting at a minimum power level P_0 which is guaranteed to be less than the required power, and quickly increases transmission power (step 204). Once the received power level at the base station 14 reaches the minimum level needed for detection of the short code (step 206) the base station 14 acquires the correct phase of the short code, transmits an indication of this detection, and begins searching for the access code (step 208). Upon receiving the detection indication, the subscriber unit 16 ceases transmitting the short code and starts transmitting an access code. The subscriber unit 16 initiates a slow ramp-up of transmit power while sending the access code (step 210). The base station 14 searches for the correct phase of the access code by searching only one phase out of each short code length portion of the access code (step 212). If the base station 14 searches the phases of the access code up to the maximum round trip delay and has not detected the correct phase, the search is repeated by searching every phase (step 214). Upon detection of the correct phase of the access code by the base station 14, the base station 14 sends an acknowledgment to the subscriber unit 16 (step 216). Reception of the acknowledgment by the subscriber unit 16 concludes the ramp-up process. A closed loop power control is established, and the subscriber unit 16 continues the call setup process by sending related call setup messages (step 218).

Although the invention has been described in part by making detailed reference to the preferred embodiment, such detail is intended to be instructive rather than restrictive. It will be appreciated by those skilled in the art that many variations may be made in the structure and mode of operation without departing from the spirit and scope of the invention as disclosed in the teachings herein.

What is claimed is:

1. A method for controlling transmission power during the establishment of communications between a base station and at least one subscriber unit, the method comprising:

transmitting a first periodic signal from said subscriber unit at an initial power level, said initial power level being lower than the power level required for detection by said base station;

increasing said power level at a first ramp-up rate;

detecting said first periodic signal at said base station when a sufficient power for detection is achieved;

transmitting a confirmation signal from said base station when said first periodic signal has been detected;

receiving said confirmation signal at said subscriber unit;

ceasing said first ramp-up rate when said confirmation signal is received, and

transmitting a second periodic signal while increasing the power level of said second periodic signal at a second

ramp-up rate, said second ramp-up rate being less than said first ramp-up rate.

2. The method of claim 1 wherein the duration of said second periodic signal is an even multiple of the duration of said first periodic signal.

3. The method of claim 1 wherein the beginning of said second periodic signal is synchronized with the beginning of said first periodic signal.

4. The method of claim 1 further including detecting, by said base station, said second periodic signal and searching for the beginning of said second periodic signal.

5. The method of claim 4 wherein said first and second periodic signals comprise a plurality of chips and wherein said base station searches every Nth chip of said second periodic signal; where N is the number of chips in said first periodic signal.

6. The method of claim 5 further including ceasing, after a predetermined duration, the search of every Nth chip when the beginning of said second periodic signal has not been determined.

7. The method of claim 6 wherein said predetermined duration is equivalent to the round trip delay of a signal sent to a subscriber unit at the maximum operating range of the system.

8. The method of claim 7 further including ceasing the increase in transmission power from said subscriber unit upon the receipt of said acknowledgment signal by said subscriber unit.

9. The method of claim 6 further including searching every chip of said second periodic signal after said predetermined duration.

10. The method of claim 6 further including transmitting an acknowledgment signal from said base station when the beginning of said second periodic signal has been detected by said base station.

11. A network for communicating between a base station and at least one subscriber unit, the network including a system for initial power control comprising:

said subscriber unit comprising:

means for selectively transmitting at least one access code at a selected transmission power level;

means for detecting a signal from said base station confirming the receipt of said access code; and

control means, responsive to said detecting means, for varying said transmission power level; wherein said control means increases said transmission power level at a first rate prior to the receipt of said confirmation signal and increases said transmission power level at a second rate after the receipt of said confirmation signal, said second rate being less than said first rate; and

said base station comprising:

means for detecting transmissions from at least one said subscriber unit, said transmissions including said access code; and

transmission means, responsive to said detecting means, for transmitting a confirmation signal to said subscriber unit when said access code is detected.

12. A method for controlling transmission power ramp-up during establishment of communications between a base station and at least one subscriber unit, the method comprising:

transmitting from said subscriber unit a first periodic signal at an initial power level, said power level being sufficiently low such that it will not be detected by said base station;

steadily increasing the power level of said signal at a first ramp-up rate;

detecting at said base station, the correct phase of said first periodic signal when the first periodic signal achieves a sufficient power for detection;

transmitting, from said base station, a confirmation signal that said first periodic signal has been detected;

receiving, at said subscriber unit, said confirmation signal;

ceasing the first power level ramp-up rate when said confirmation signal is received; and

transmitting from said subscriber unit a second periodic signal while increasing the power level of said second periodic signal at a second ramp-up rate; said second ramp-up rate being less than said first ramp-up rate.

13. The method of claim 12 wherein the duration of said second periodic signal is an even multiple of said first periodic signal.

14. The method of claim 13 wherein the beginning of said second periodic signal is synchronized with the beginning of said first periodic signal.

15. The method of claim 12 further including detecting, by said base station, said second periodic signal and searching for the beginning of said second periodic signal.

16. The method of claim 15 wherein said base station searches every Nth chip of said second periodic signal and N is the length of said first periodic signal.

17. The method of claim 16 further including ceasing, after a predetermined duration, searching by said base station of every N chips of said second periodic signal when the beginning of said second periodic signal has not been determined, said predetermined duration being equivalent to the round trip delay of a signal sent to a subscriber unit at the maximum operating range of the system.

18. The method of claim 17 further including searching, by said base station, every chip of said second periodic signal after said predetermined duration.

19. The method of claim 17, further including transmitting an acknowledgment signal from said base station to said subscriber unit when said second periodic signal has been detected at said base station.

20. The method of claim 19 further including ceasing increasing transmission power from said subscriber unit when said acknowledgment signal is received at said subscriber unit.

21. A communication system for communicating between a base station and at least one subscriber unit, said communication system including a system for initial power control, said power control system comprising:

said subscriber unit comprising:

means for periodically transmitting a short access code having a predetermined length to said base station; said short access code being transmitted at a first power level;

means for increasing said power level at a first power ramp-up rate;

means for detecting a transmission from said base station which confirms the receipt of said short access code at said base station; and

means, responsive to said detecting means, for periodically transmitting a long access code a second increasing power ramp-up rate; said long access code having a predetermined length which is an even multiple of said short access code said second ramp-up rate being less than said first power increase rate; and

said base station comprising:

means for detecting transmissions from at least one said subscriber unit including said short and long access codes; and

transmission means, responsive to said detecting means, for transmitting a confirmation signal to said subscriber unit when said access codes are detected.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,841,768

DATED : November 24, 1998

INVENTOR(S) : Ozluturk et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title page item [75] delete "Faith" and insert therefor --Fatih--.

At column 4, line 45, after the word "delay" delete "At" and insert therefor --Δt--.

In claim 1, at column 10, line 65, delete "received," and insert therefor --received;--.

In claim 19, at column 12, line 31, after "claim" delete "17," and insert therefor --17--.

In claim 21, at column 12, line 53, after "code" insert --at--.

In claim 21, at column 12, line 56, after "code" insert --;--.

In Figure 6A, should be deleted to appear as per attached sheet.

Signed and Sealed this

Fourteenth Day of September, 1999

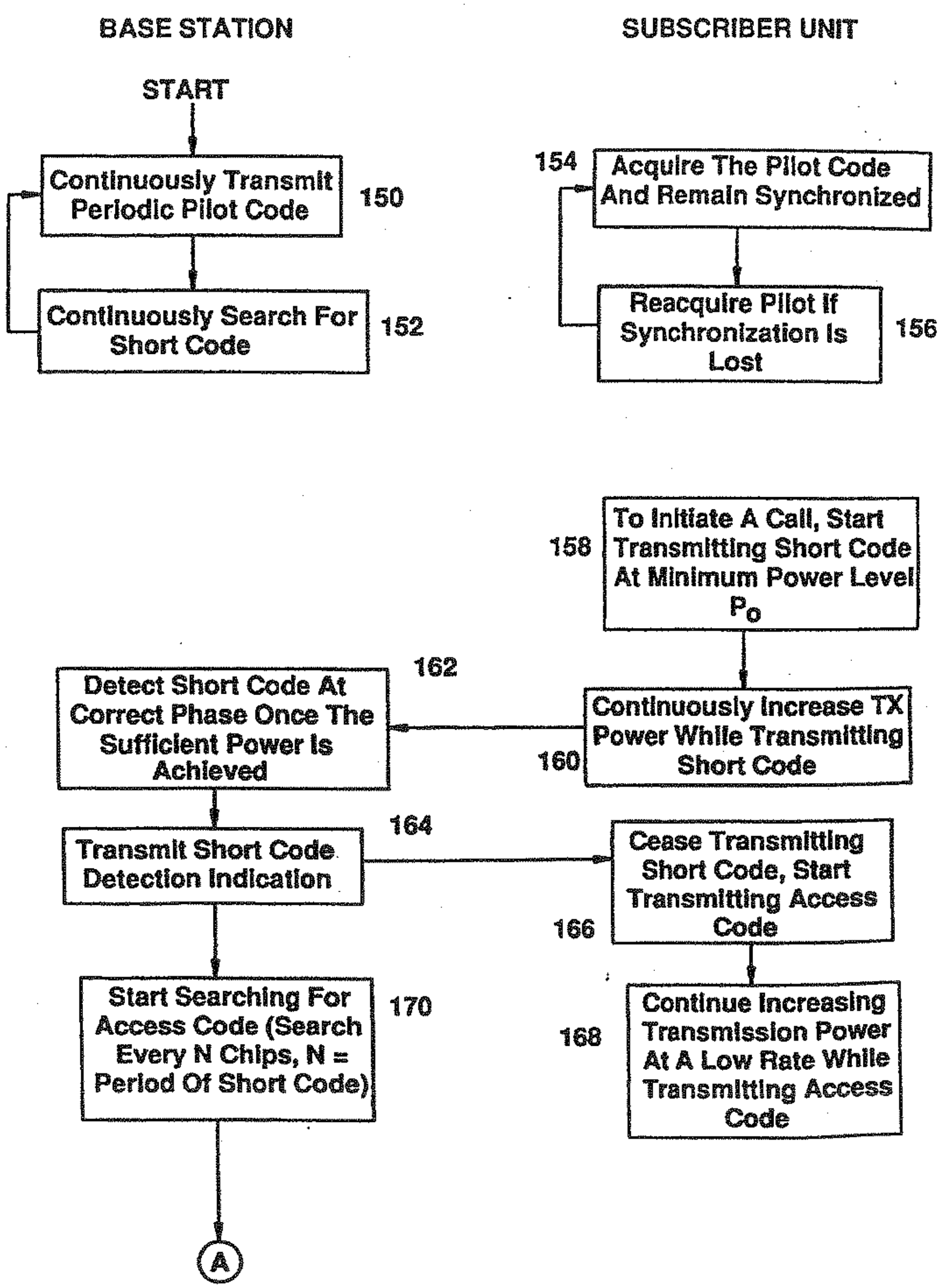
Attest:

Q. TODD DICKINSON

Attesting Officer

Acting Commissioner of Patents and Trademarks

FIG.6A


BASE STATION
SUBSCRIBER UNIT
START
Continuously Transmit Periodic Pilot Code
150
Continuously Search For Short Code
152
154
Acquire The Pilot Code And Remain Synchronized
Reacquire Pilot If Synchronization Is Lost
156
158
To Initiate A Call, Start Transmitting Short Code At Minimum Power Level P_o
162
Detect Short Code At Correct Phase Once The Sufficient Power Is Achieved
Continuously Increase TX Power While Transmitting Short Code
160
164
Transmit Short Code Detection Indication
Cease Transmitting Short Code, Start Transmitting Access Code
166
Start Searching For Access Code (Search Every N Chips, N = Period Of Short Code)
170
168
Continue Increasing Transmission Power At A Low Rate While Transmitting Access Code
A

US006215778B1

(12) **United States Patent**
Lomp et al.

(10) **Patent No.: US 6,215,778 B1**
(45) **Date of Patent: Apr. 10, 2001**

(54) **BEARER CHANNEL MODIFICATION SYSTEM FOR A CODE DIVISION MULTIPLE ACCESS (CDMA) COMMUNICATION SYSTEM**

(75) Inventors: **Gary Lomp**, Centerpot; **John Kowalski**, Hempstead; **Fatih Ozluturk**, Port Washington; **Avi Silverberg**, Commack; **Robert Regis**, Huntington; **Michael Luddy**, Sea Cliff; **Alexander Marra**, New York; **Alexander Jacques**, Mineola, all of NY (US)

(73) Assignee: **InterDigital Technology Corporation**, Wilmington, DE (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **08/956,740**

(22) Filed: **Oct. 23, 1997**

Related U.S. Application Data

(62) Division of application No. 08/669,775, filed on Jun. 27, 1996, now Pat. No. 5,799,010.
(60) Provisional application No. 60/000,775, filed on Jun. 30, 1995.

(51) **Int. Cl.**^{7} **H04B 7/216**
(52) **U.S. Cl.** **370/335**; 370/465
(58) **Field of Search** 370/310, 318, 370/320, 328, 329, 335, 342, 465, 468, 477, 441, 479, 503, 515; 375/140, 146, 147, 354, 367

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(List continued on next page.)

Primary Examiner—Wellington Chin
Assistant Examiner—Kwang B. Yao
(74) *Attorney, Agent, or Firm*—Volpe and Koenig, P.C.

(57) **ABSTRACT**

A multiple access, spread-spectrum communication system processes a plurality of information signals received by a Radio Carrier Station (RCS) over telecommunication lines for simultaneous transmission over a radio frequency (RF) channel as a code-division-multiplexed (CDM) signal to a group of Subscriber Units (SUs). The RCS receives a call request signal that corresponds to a telecommunication line information signal, and a user identification signal that identifies a user to receive the call. The RCS includes a plurality of Code Division Multiple Access (CDMA) modems, one of which provides a global pilot code signal. The modems provide message code signals synchronized to the global pilot signal. Each modem combines an information signal with a message code signal to provide a CDM processed signal. The RCS includes a system channel controller is coupled to receive a remote call. An RF transmitter is connected to all of the modems to combine the CDM processed signals with the global pilot code signal to generate a CDM signal. The RF transmitter also modulates a carrier signal with the CDM signal and transmits the modulated carrier signal through an RF communication channel to the SUs. Each SU includes a CDMA modem which is also synchronized to the global pilot signal. The CDMA modem despreads the CDM signal and provides a despread information signal to the user. The system includes a closed loop power control system for maintaining a minimum system transmit power level for the RCS and the SUs, and system capacity management for maintaining a maximum number of active SUs for improved system performance.

6 Claims, 37 Drawing Sheets

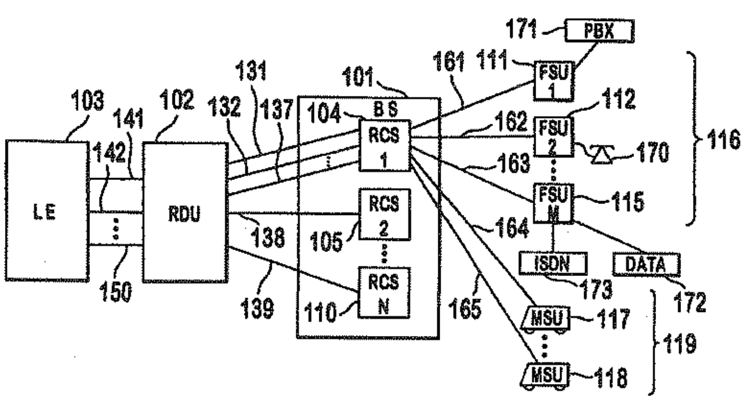

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FIG. 1

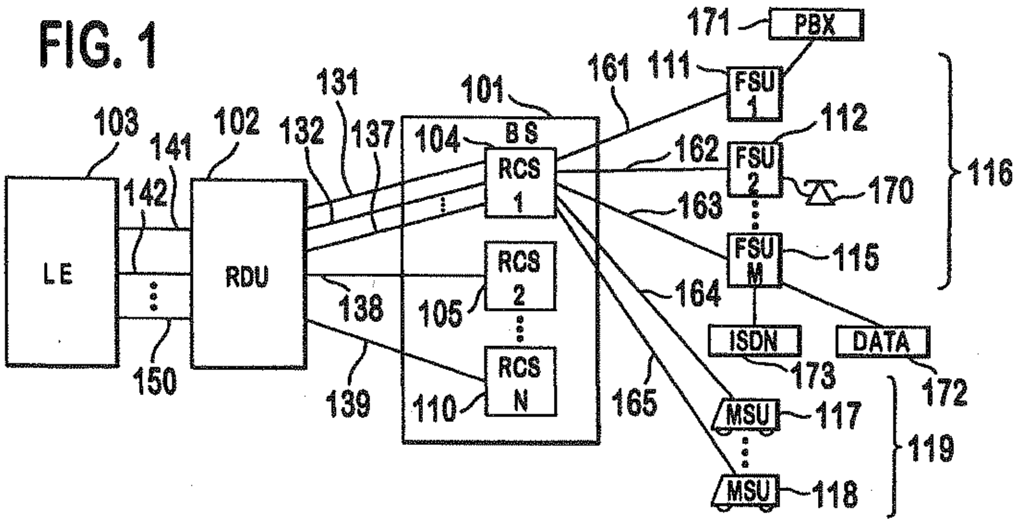


FIG. 2a

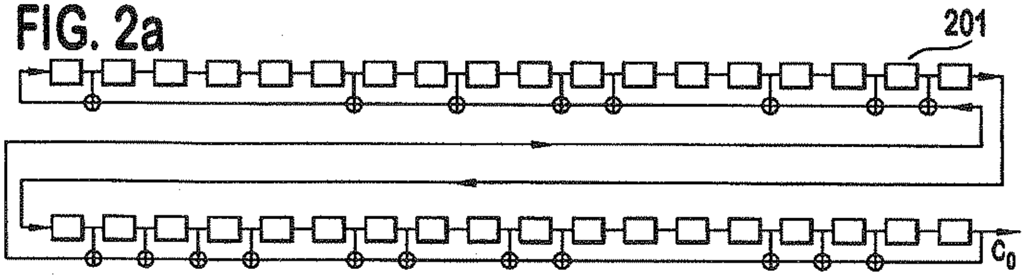
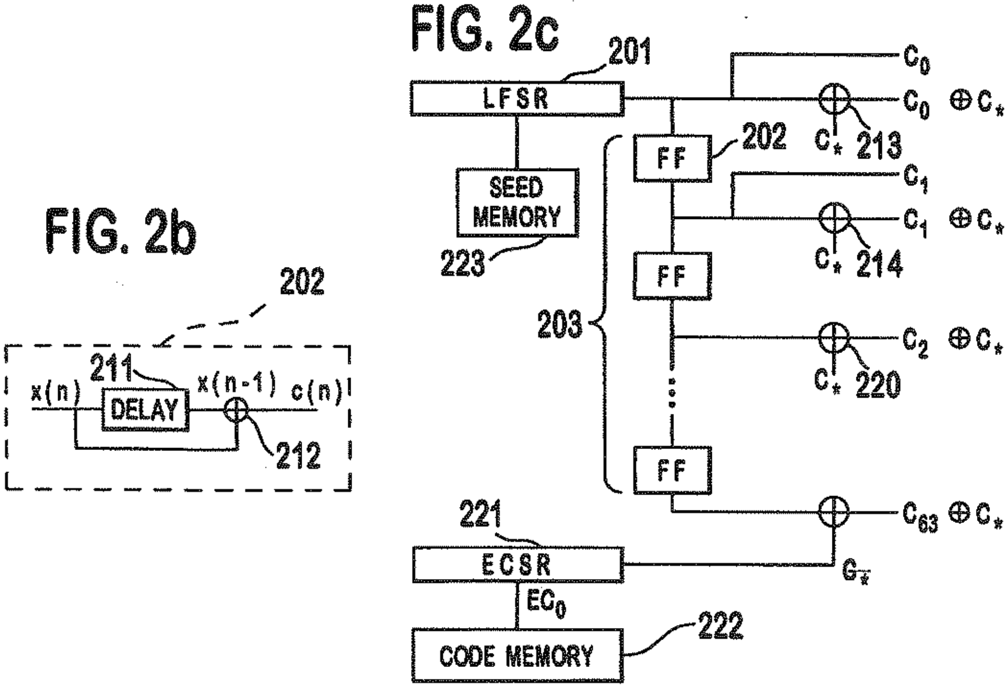


FIG. 2b

FIG. 2c



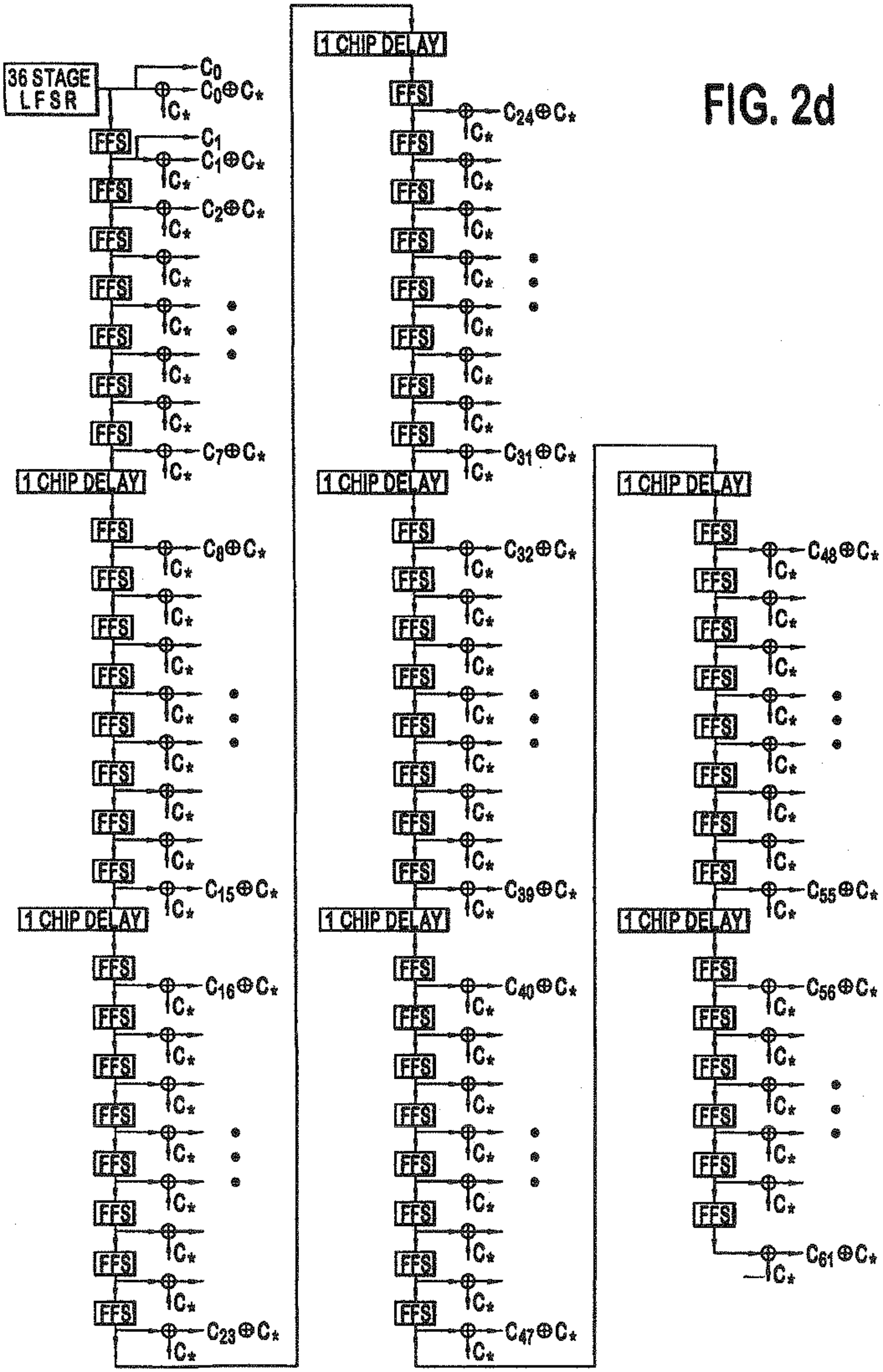

36 STAGE LFSR
1 CHIP DELAY
FFS
C0
C0⊕C*
C1
C1⊕C*
C2⊕C*
C7⊕C*
C8⊕C*
C15⊕C*
C16⊕C*
C23⊕C*
C24⊕C*
C31⊕C*
C32⊕C*
C39⊕C*
C40⊕C*
C47⊕C*
C48⊕C*
C55⊕C*
C56⊕C*
C61⊕C*
C*

FIG. 2d

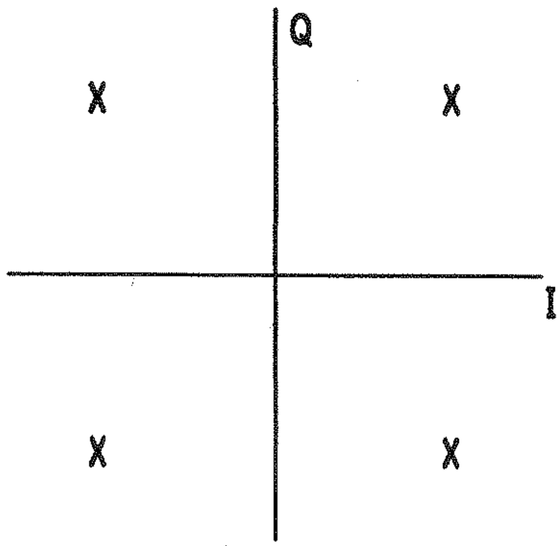


FIG. 3a

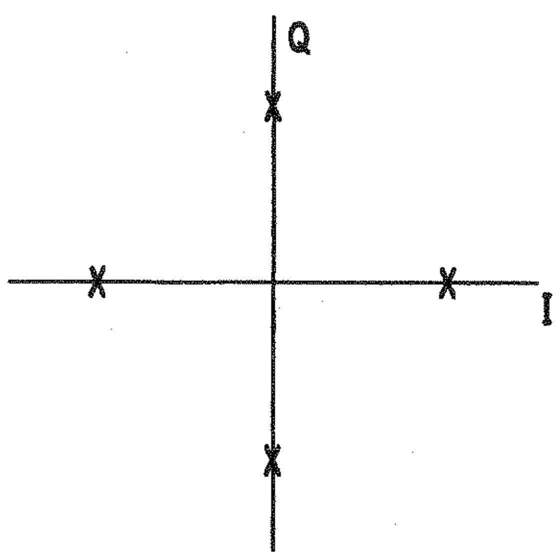


FIG. 3b

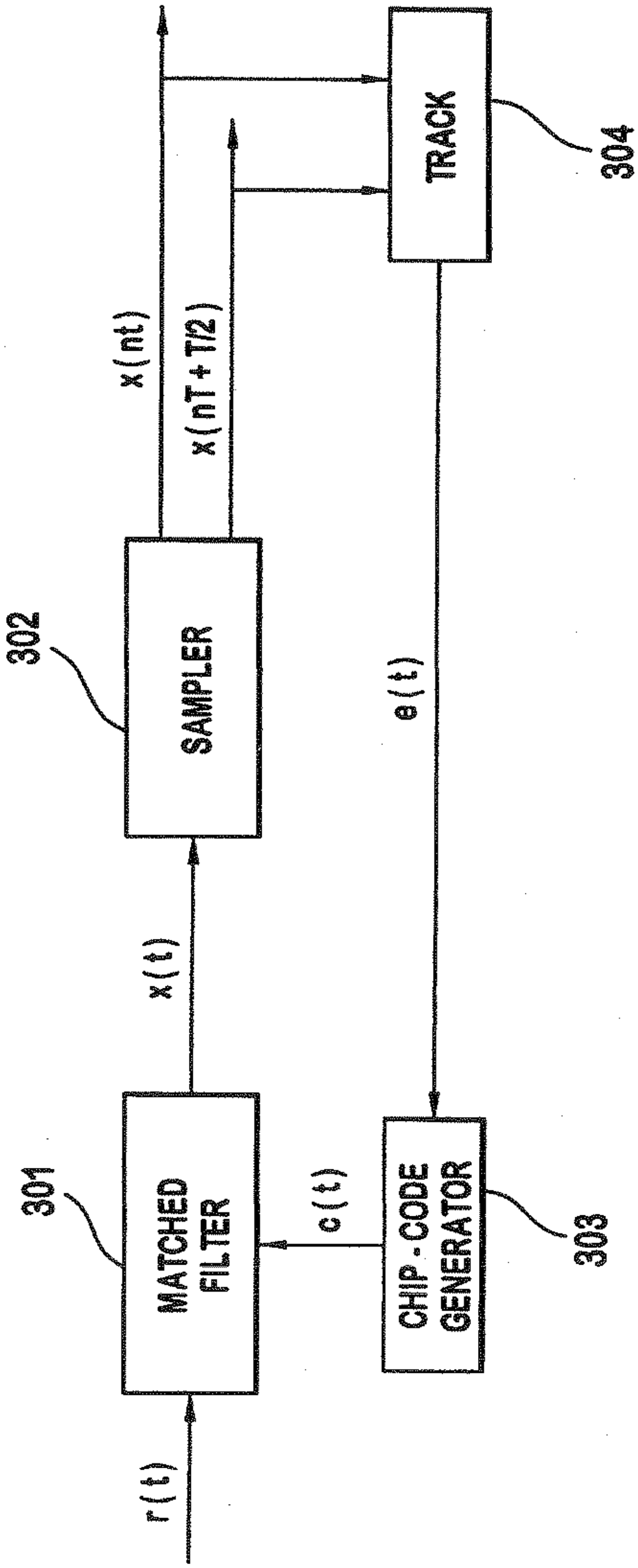

r(t)
MATCHED FILTER
301
x(t)
c(t)
CHIP-CODE GENERATOR
303
SAMPLER
302
e(t)
x(nt)
x(nT + T/2)
TRACK
304

FIG. 3c

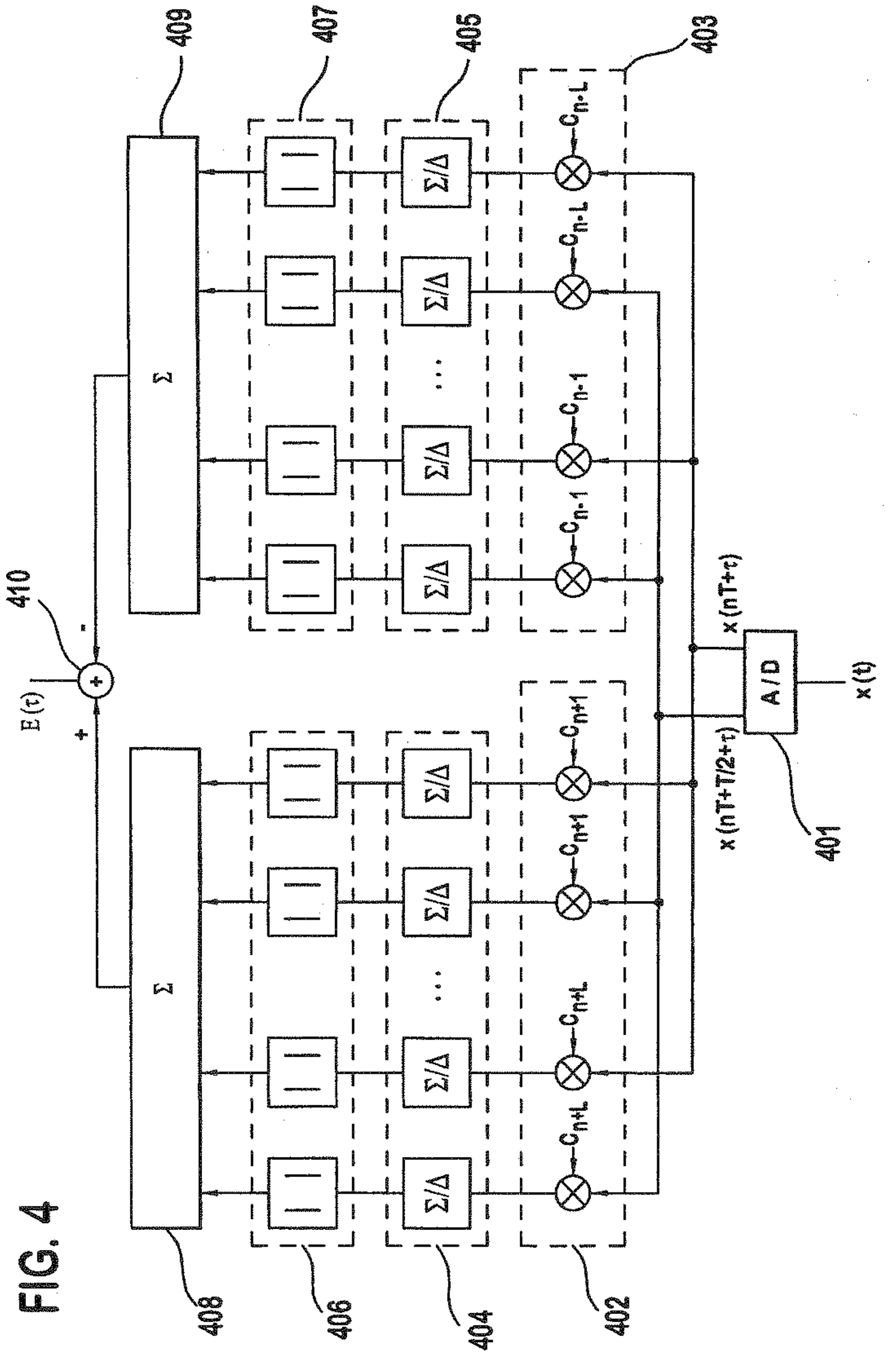

409
407
405
403
410
E(τ)
+
-
Σ
Σ
Σ/Δ
C_{n-L}
C_{n-1}
C_{n+1}
C_{n+L}
x (nT+τ)
x (nT+T/2+τ)
A / D
x (t)
401
408
406
404
402

FIG. 4

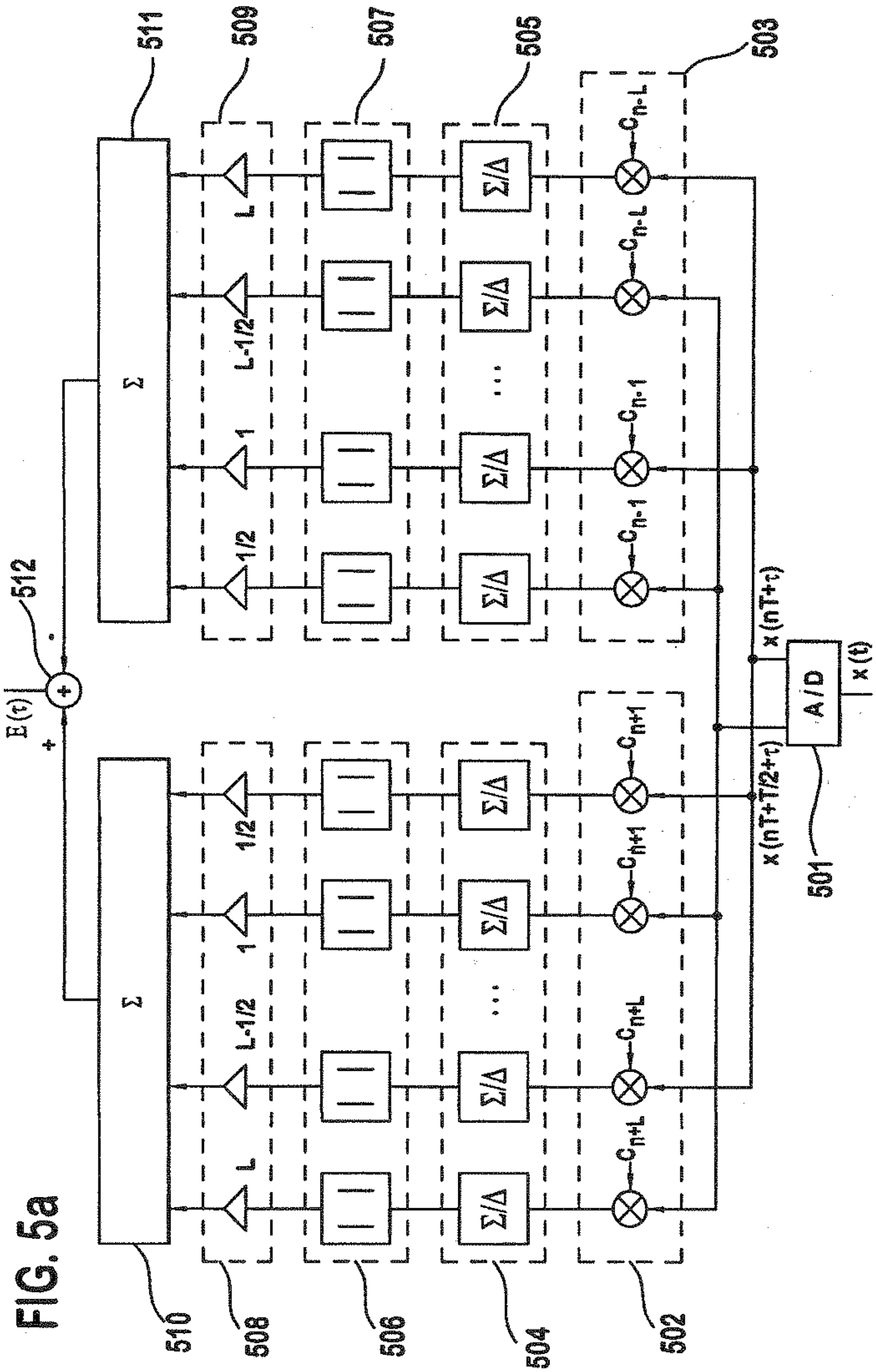
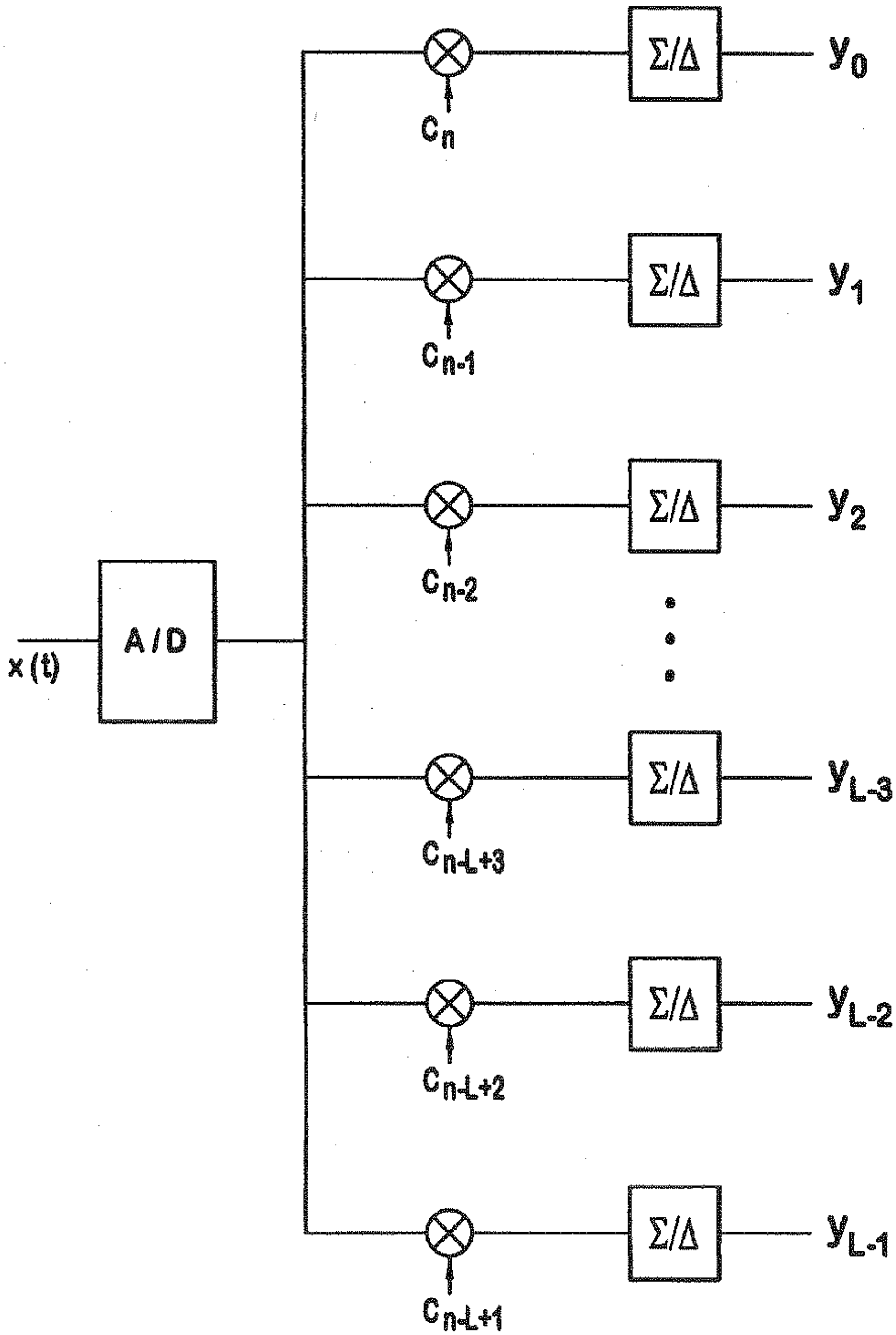

511
509
507
505
503
512
501
510
508
506
504
502
Σ
Σ
E(τ)
+
-
A / D
x (t)
x (nT+τ)
x (nT+T/2+τ)
Σ/Δ
L
L-1/2
1
1/2
c_{n-L}
c_{n-1}
c_{n+1}
c_{n+L}

FIG. 5a

FIG. 5b



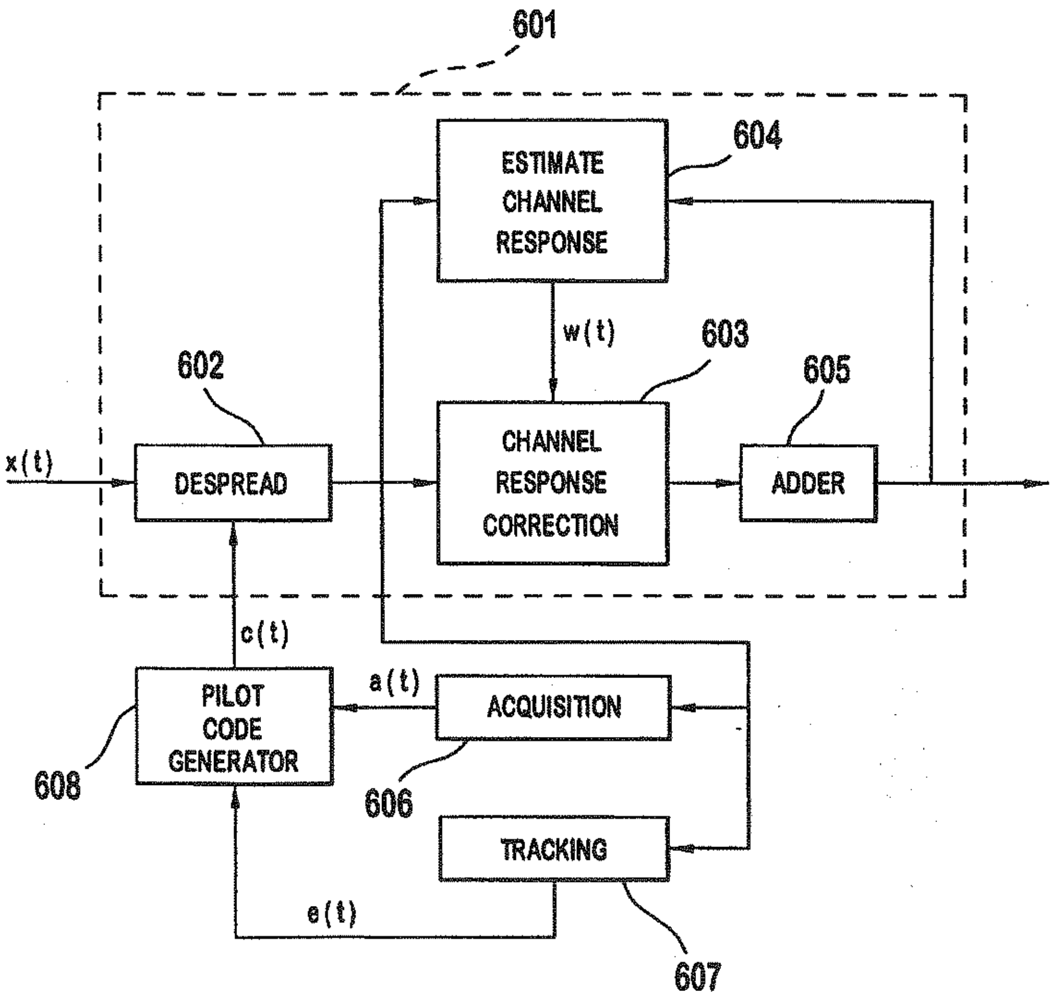

601
604
ESTIMATE CHANNEL RESPONSE
w(t)
603
605
602
x(t)
DESPREAD
CHANNEL RESPONSE CORRECTION
ADDER
c(t)
PILOT CODE GENERATOR
a(t)
ACQUISITION
608
606
TRACKING
e(t)
607

FIG. 6

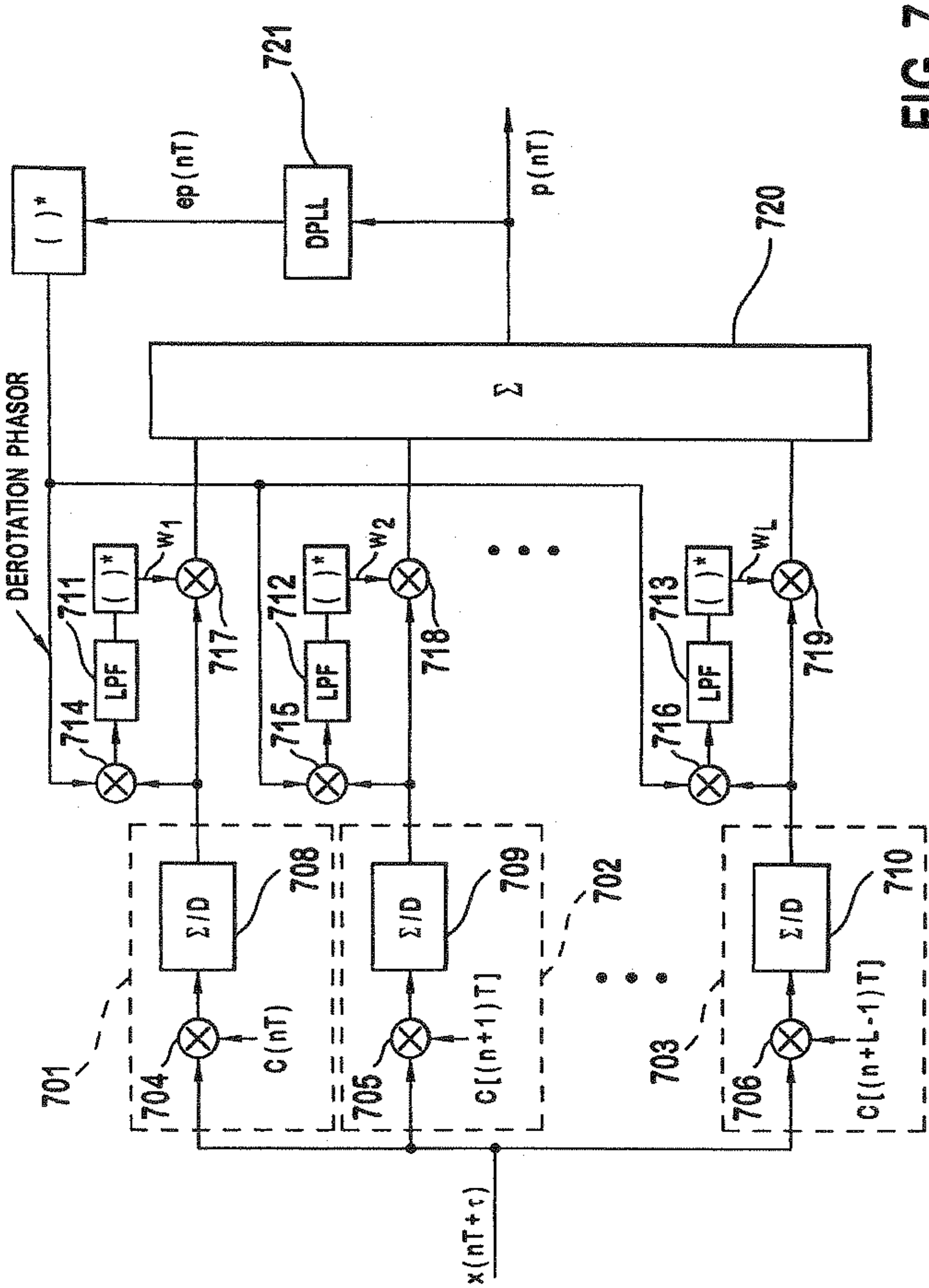
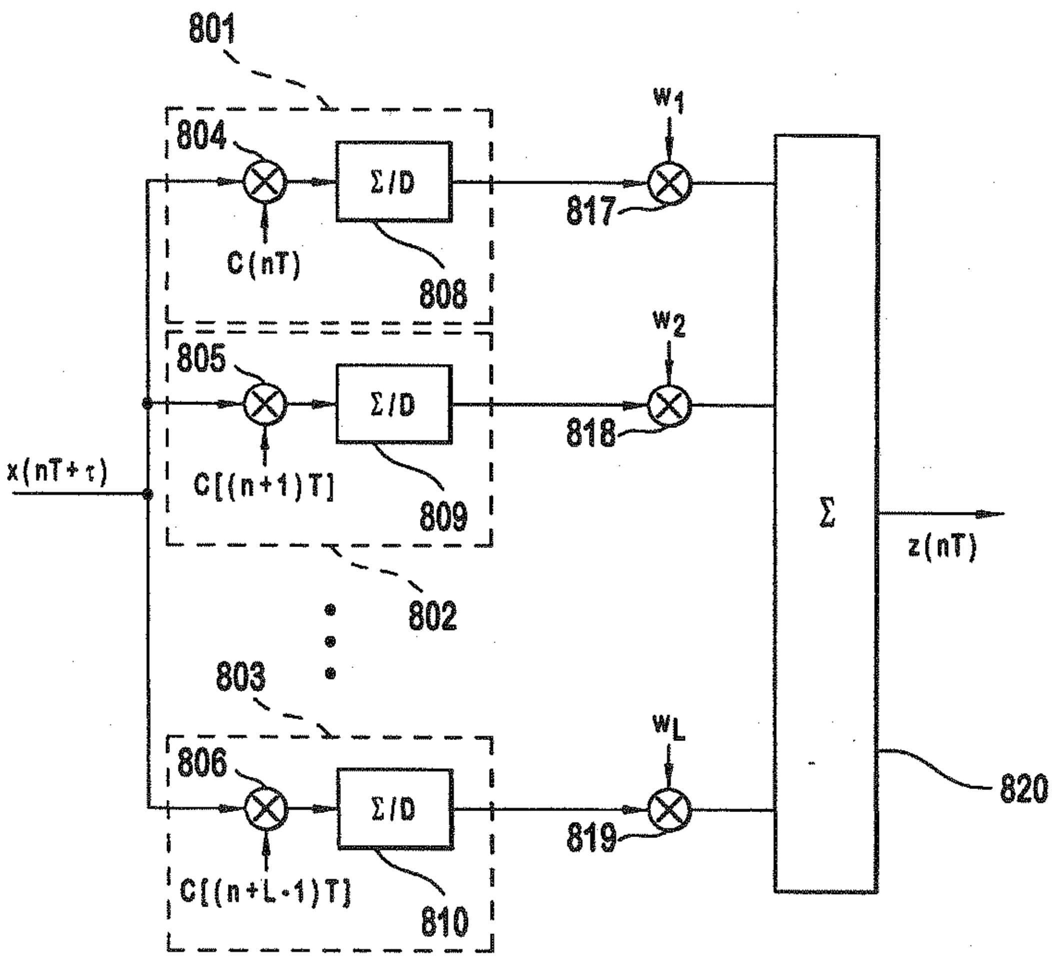
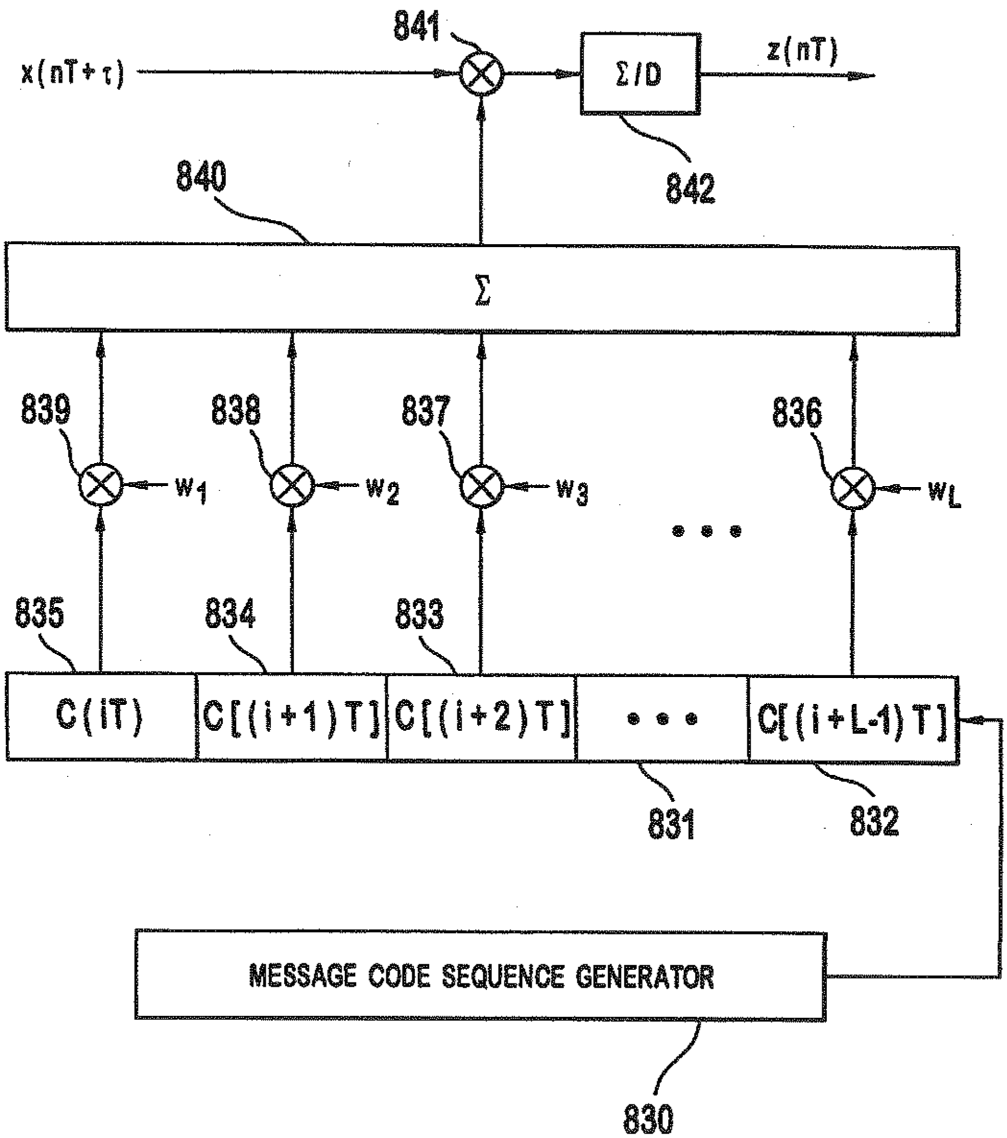

721
DPLL
ep(nT)
( )*
p(nT)
720
Σ
DEROTATION PHASOR
711
712
713
714
715
716
717
718
719
LPF
( )*
W1
W2
WL
Σ/D
708
709
710
701
702
703
704
705
706
C(nT)
C[(n+1)T]
C[(n+L-1)T]
x(nT+τ)

FIG. 7



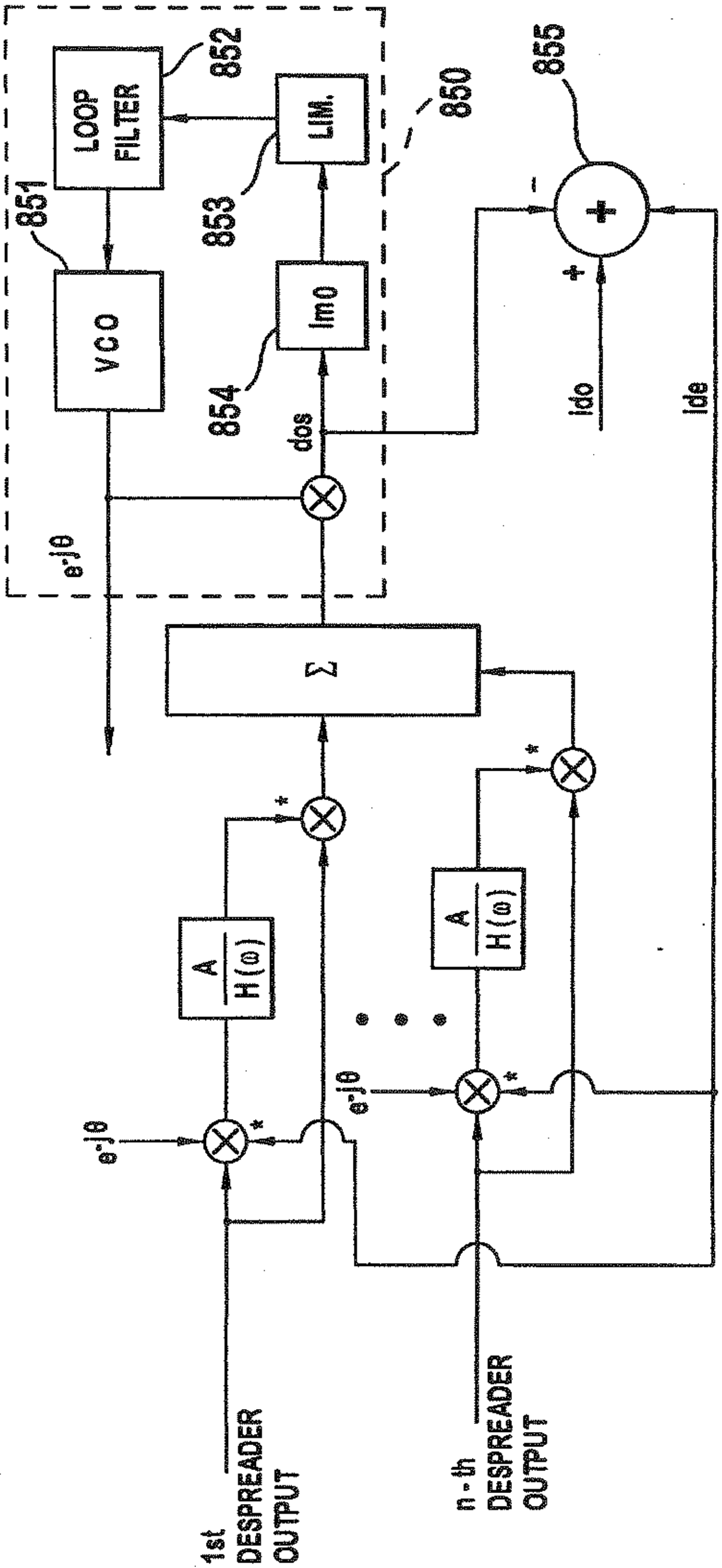
801
804
Σ/D
C(nT)
808
w_1
817
805
Σ/D
C[(n+1)T]
809
w_2
818
x(nT+τ)
802
803
806
Σ/D
C[(n+L-1)T]
810
w_L
819
Σ
z(nT)
820

FIG. 8a



841
x(nT+τ)
Σ/D
z(nT)
842
840
Σ
839
838
837
836
w1
w2
w3
wL
835
834
833
C(iT)
C[(i+1)T]
C[(i+2)T]
C[(i+L-1)T]
831
832
MESSAGE CODE SEQUENCE GENERATOR
830

FIG. 8b



LOOP FILTER
852
LIM.
850
855
851
853
VCO
Im0
854
dos
Ido
Ide
$e^{-j\theta}$
Σ
A
H(ω)
1st DESPREADER OUTPUT
n-th DESPREADER OUTPUT

FIG. 8C

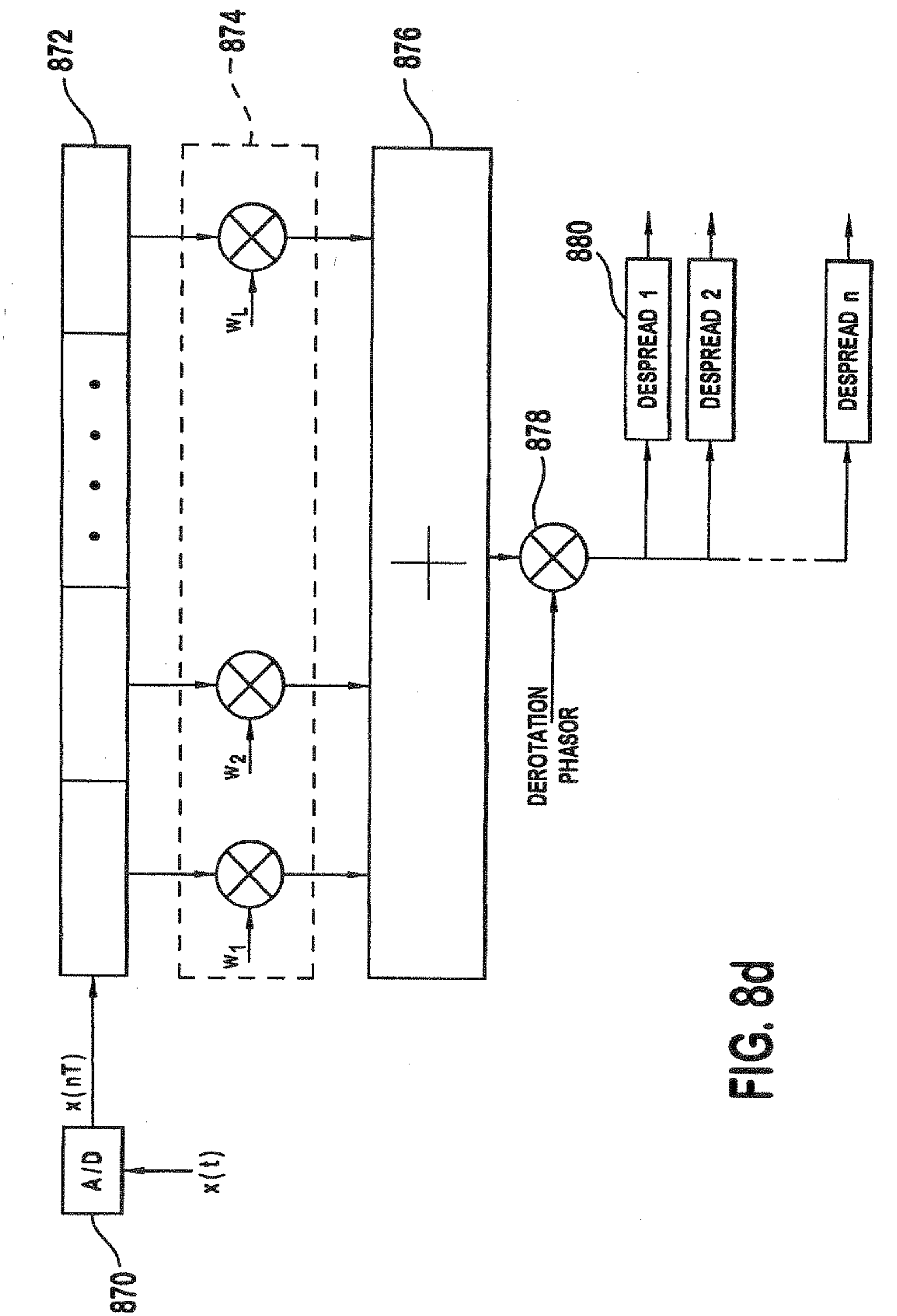

870
A/D
x(t)
x(nT)
872
874
w_1
w_2
w_L
876
878
DEROTATION PHASOR
880
DESPREAD 1
DESPREAD 2
DESPREAD n

FIG. 8d

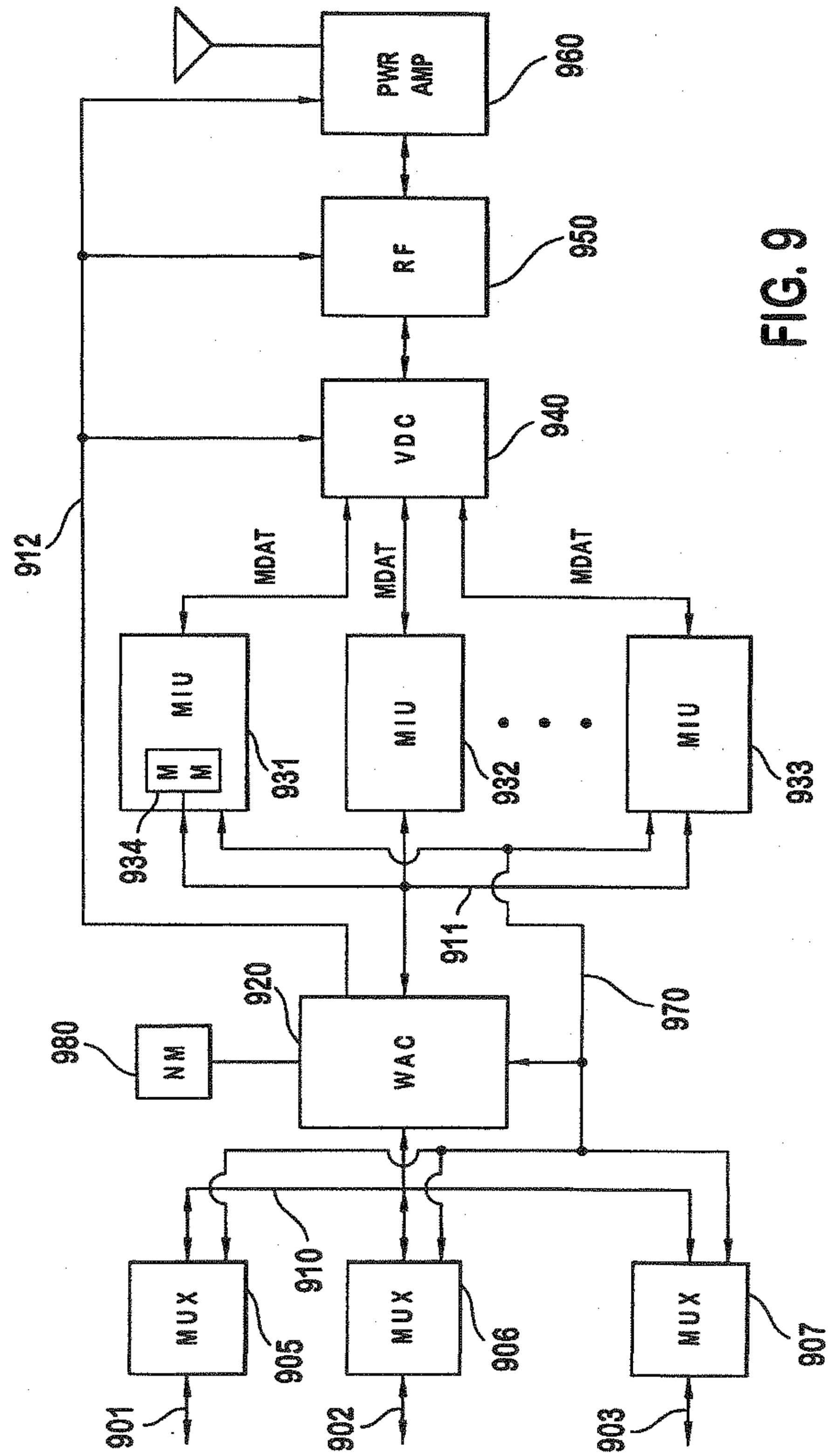

PWR AMP
960
RF
950
VDC
940
912
MDAT
MDAT
MDAT
MIU
MM
931
934
MIU
932
MIU
933
911
920
970
980
NM
WAC
910
MUX
905
MUX
906
MUX
907
901
902
903

FIG. 9

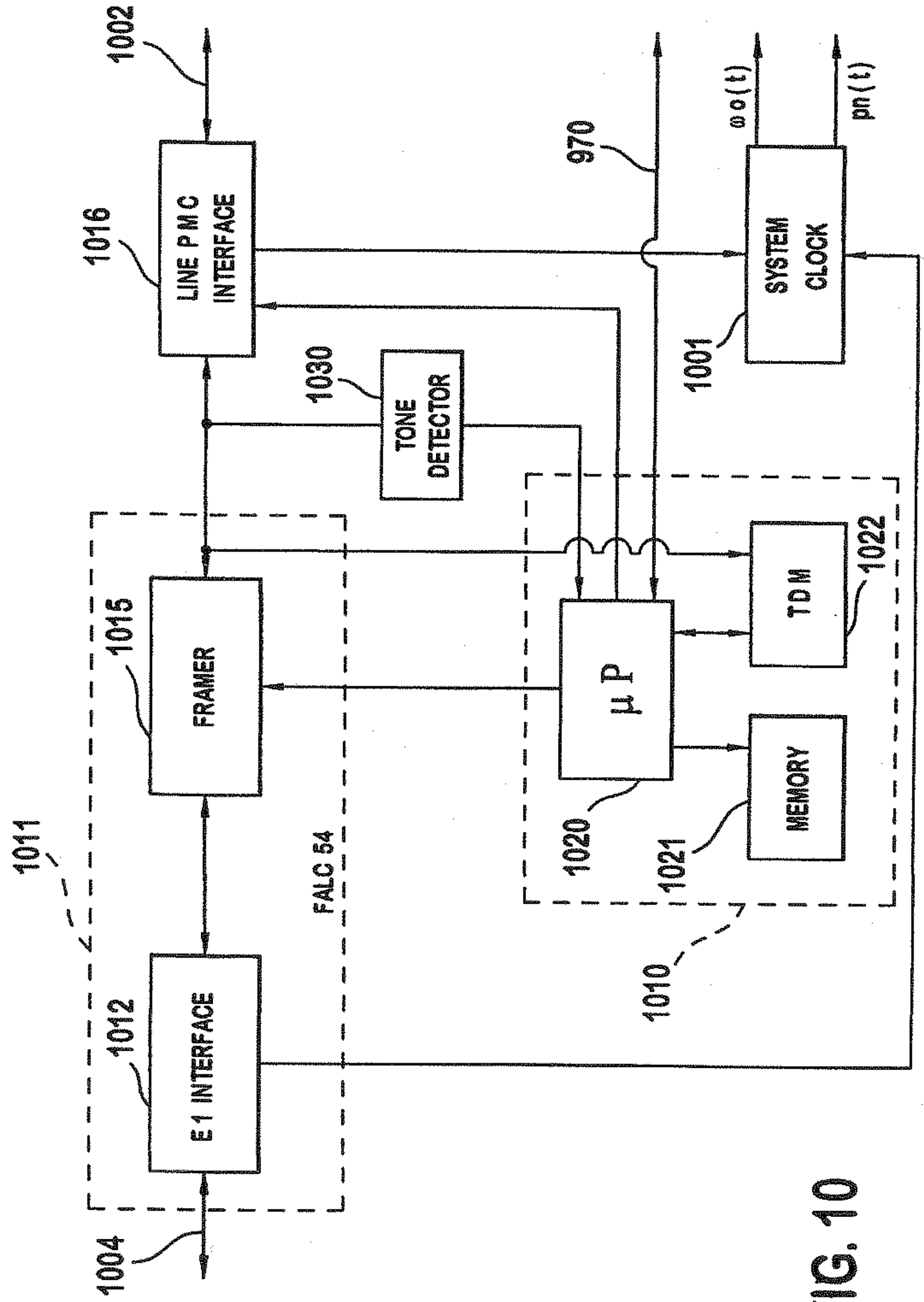
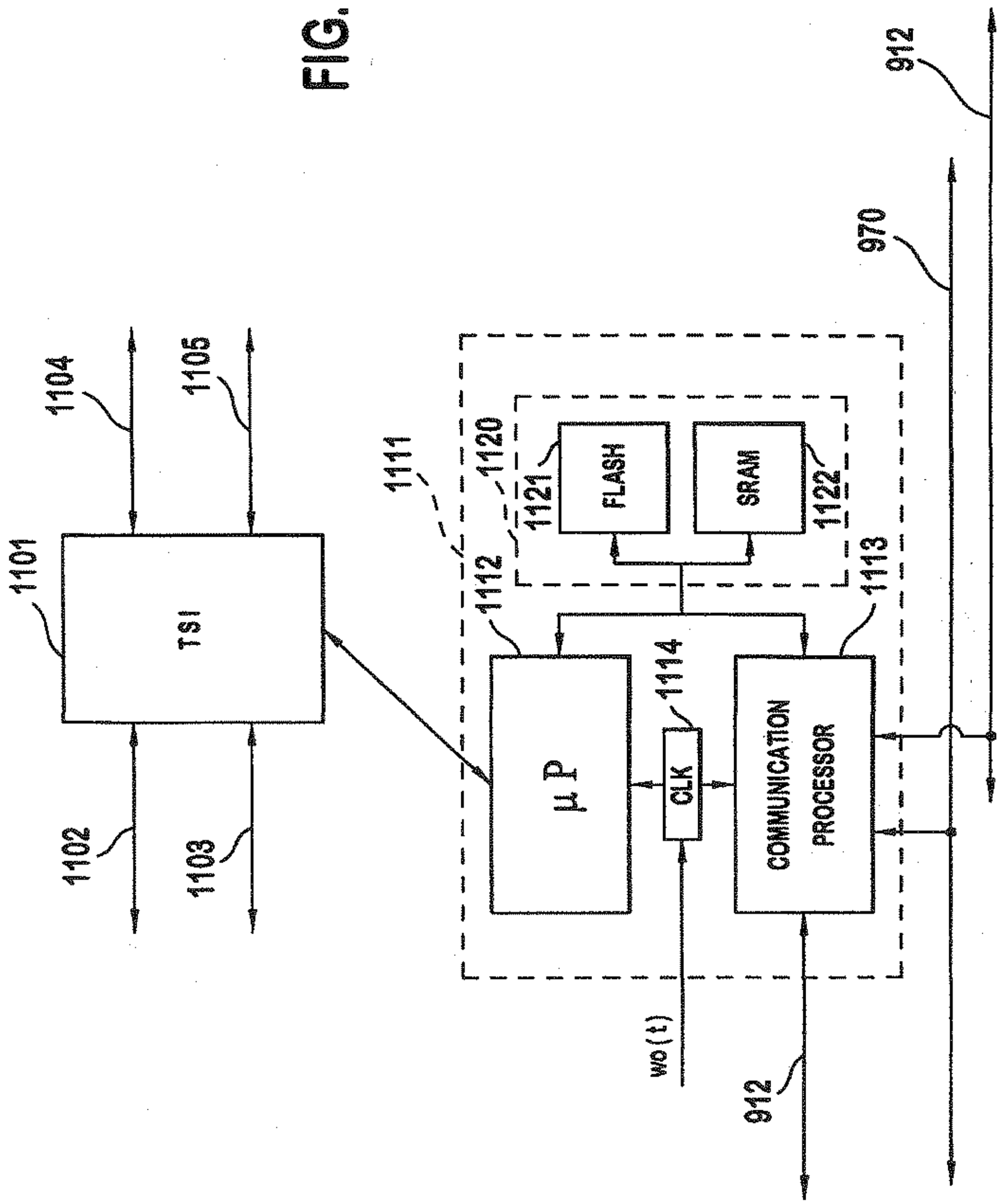

1002
1016
LINE PMC INTERFACE
970
ωo(t)
pn(t)
SYSTEM CLOCK
1001
1030
TONE DETECTOR
1015
FRAMER
TDM
1022
μP
1020
MEMORY
1021
FALC 54
1011
1012
E1 INTERFACE
1010
1004

FIG. 10

FIG. 11


1101
TSI
1102
1103
1104
1105
1111
1112
μP
1113
COMMUNICATION PROCESSOR
1114
CLK
1120
1121
FLASH
1122
SRAM
wo(t)
912
970
912

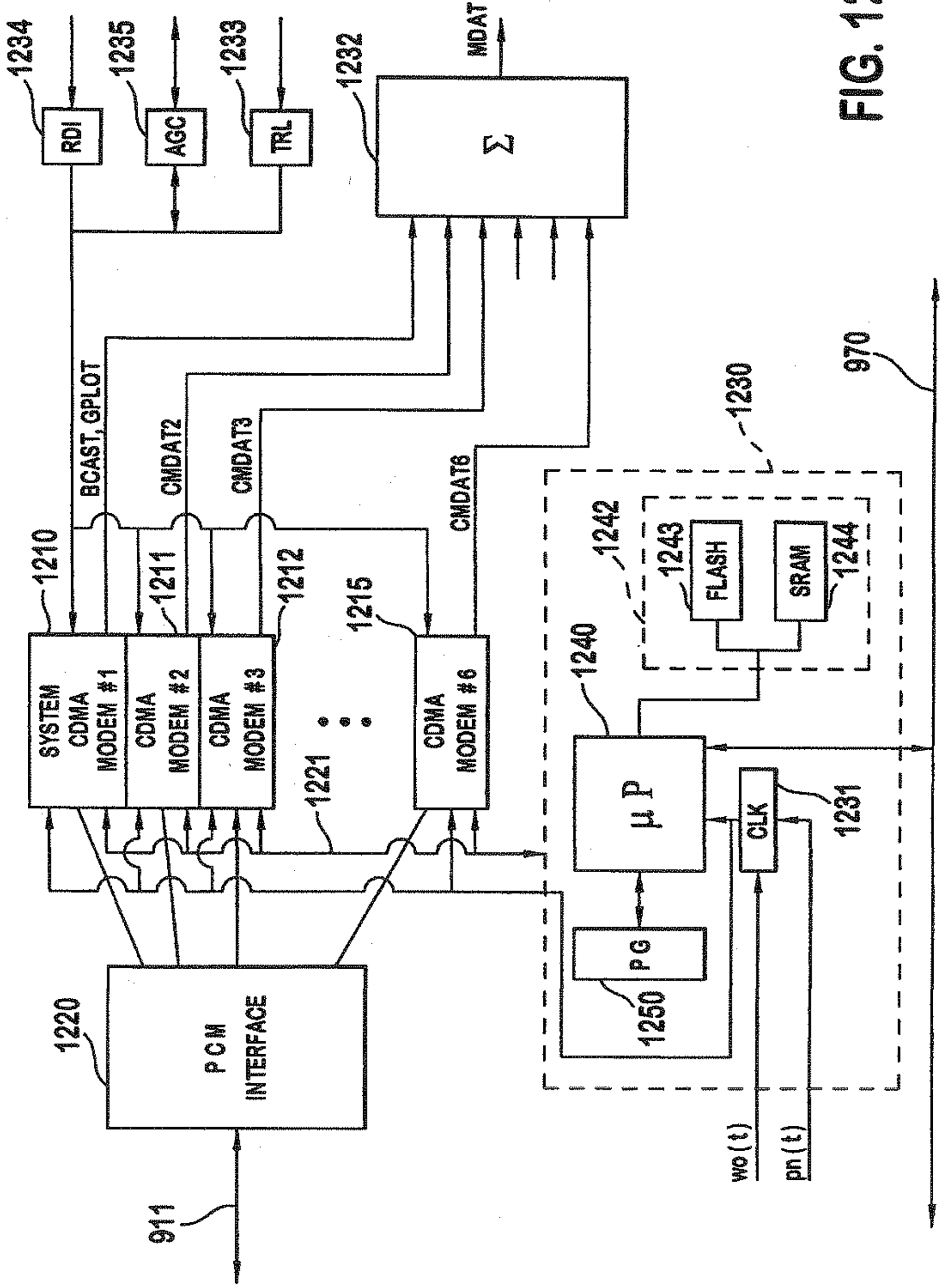

1234
RDI
1235
AGC
1233
TRL
1232
MDAT
Σ
BCAST, GPLOT
CMDAT2
CMDAT3
CMDAT6
1210
1211
1212
1215
SYSTEM CDMA MODEM #1
CDMA MODEM #2
CDMA MODEM #3
CDMA MODEM #6
1221
1220
P C M INTERFACE
911
1230
1242
1243
FLASH
SRAM
1244
1240
μ P
CLK
1231
P G
1250
wo (t)
pn (t)
970

FIG. 12

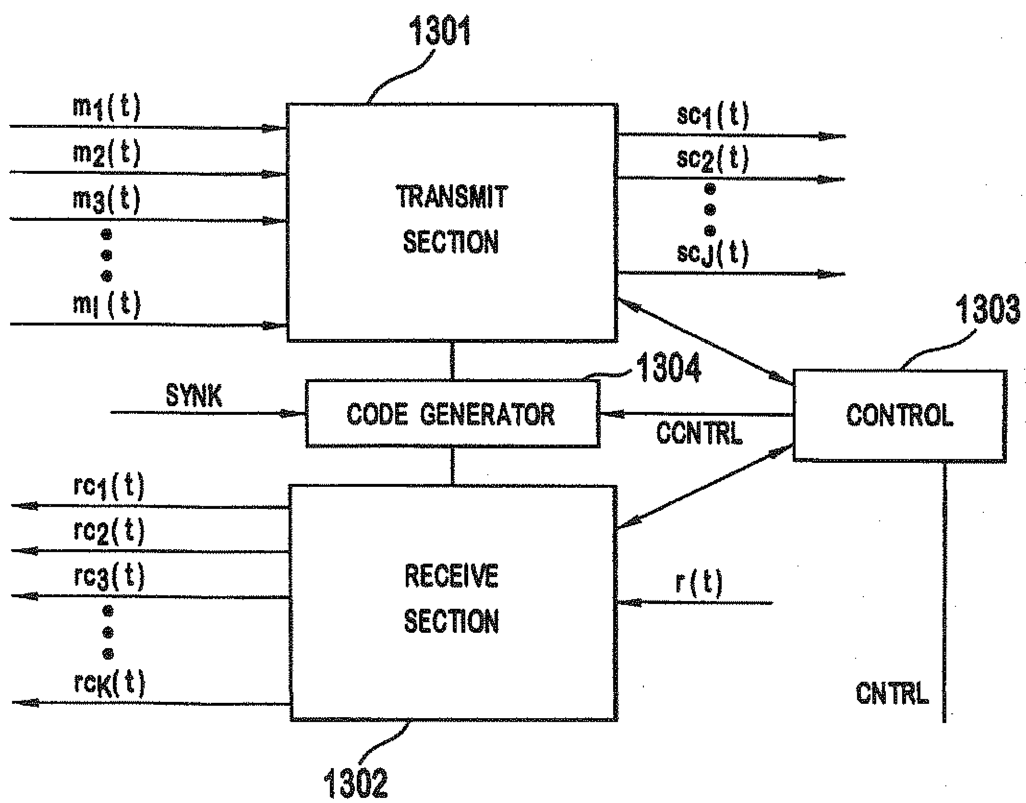
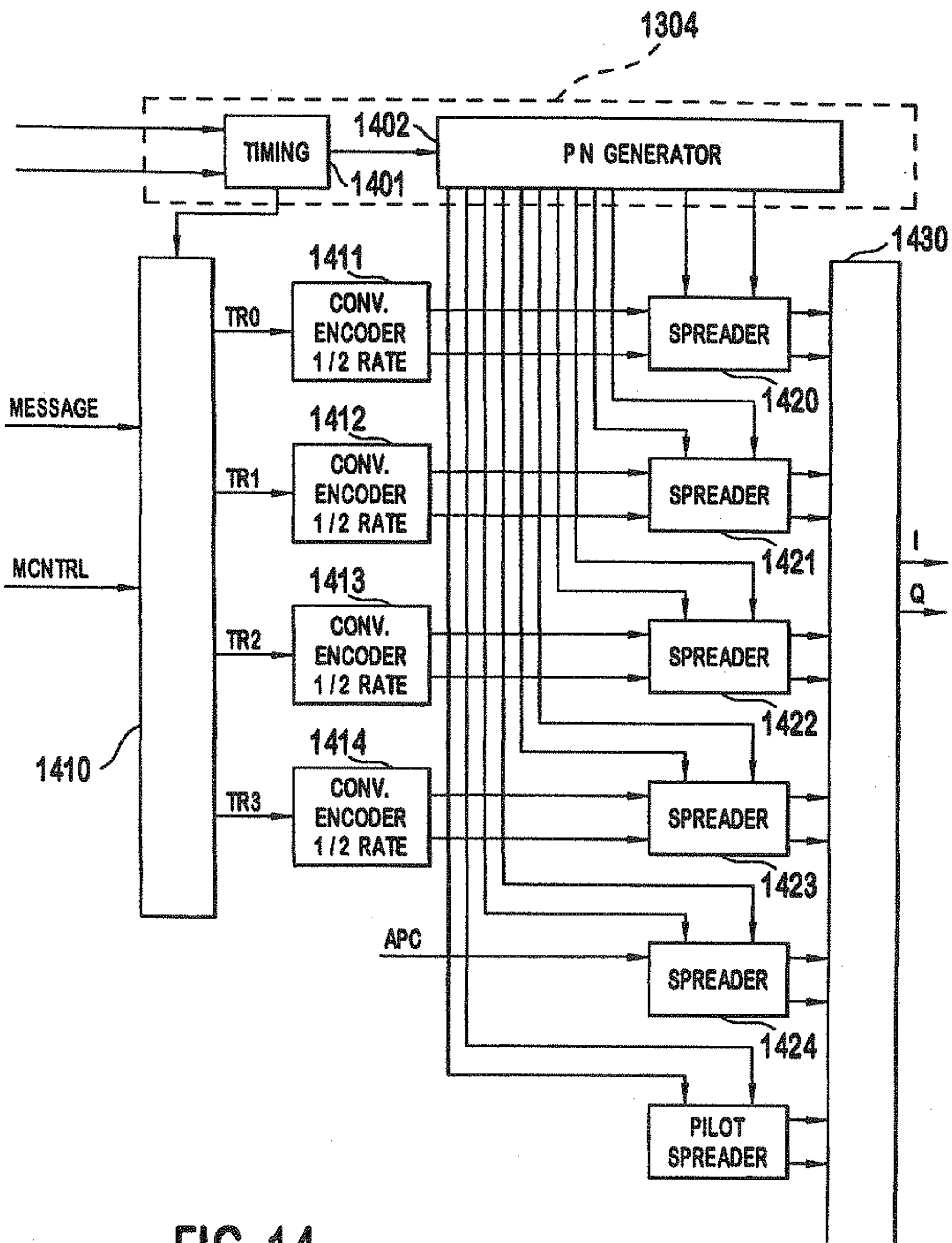

1301
m1(t)
m2(t)
m3(t)
mI(t)
TRANSMIT SECTION
sc1(t)
sc2(t)
scJ(t)
1303
1304
SYNK
CODE GENERATOR
CCNTRL
CONTROL
rc1(t)
rc2(t)
rc3(t)
rcK(t)
RECEIVE SECTION
r(t)
CNTRL
1302

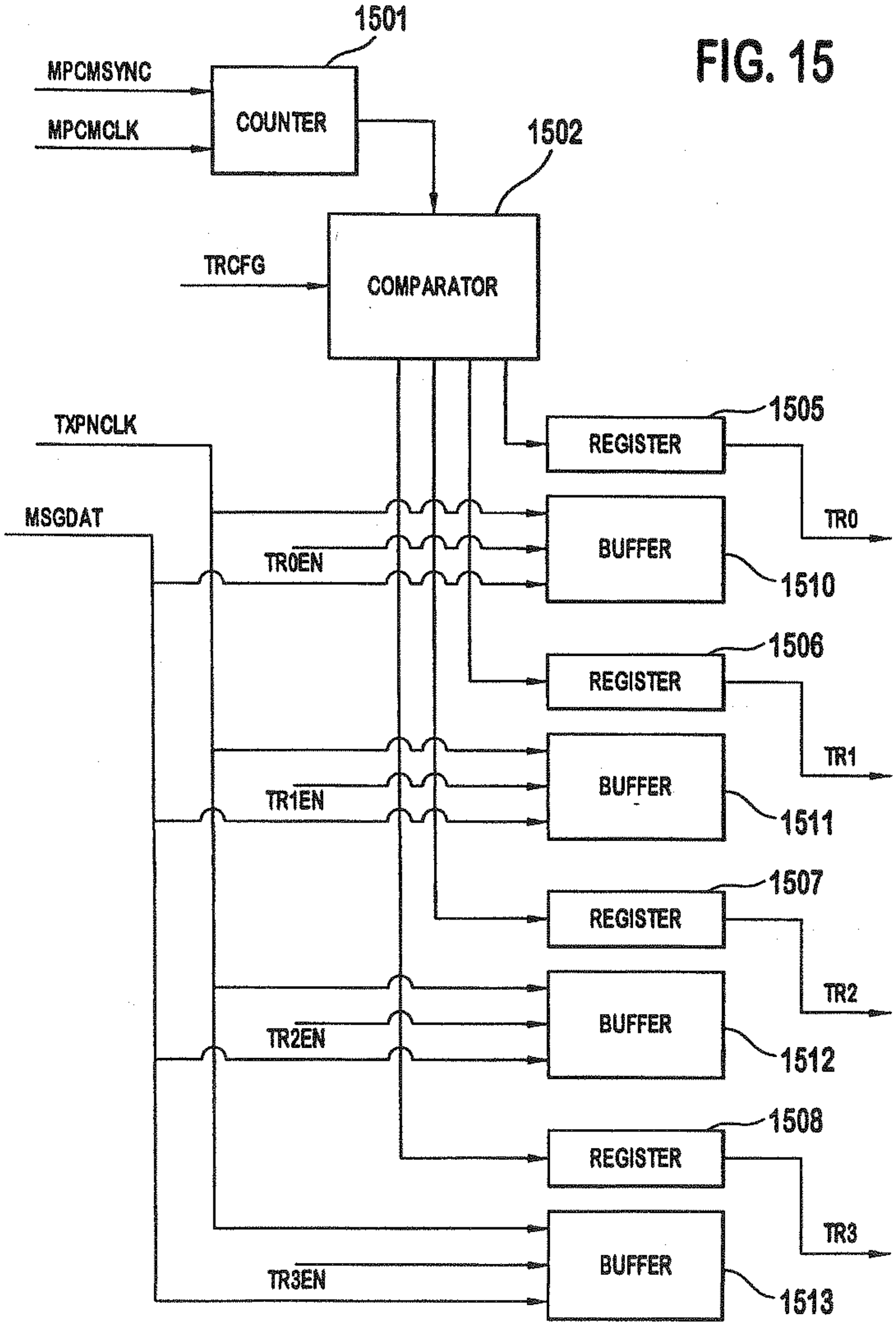
FIG. 13



1304
TIMING
1402
P N GENERATOR
1401
1430
1411
CONV. ENCODER 1/2 RATE
TR0
SPREADER
1420
MESSAGE
1412
CONV. ENCODER 1/2 RATE
TR1
SPREADER
1421
MCNTRL
I
Q
1413
CONV. ENCODER 1/2 RATE
TR2
SPREADER
1422
1410
1414
CONV. ENCODER 1/2 RATE
TR3
SPREADER
1423
APC
SPREADER
1424
PILOT SPREADER

FIG. 14

FIG. 15


1501
MPCMSYNC
MPCMCLK
COUNTER
1502
TRCFG
COMPARATOR
TXPNCLK
MSGDAT
1505
REGISTER
TR0
TR0EN
BUFFER
1510
1506
REGISTER
TR1
TR1EN
BUFFER
1511
1507
REGISTER
TR2
TR2EN
BUFFER
1512
1508
REGISTER
TR3
TR3EN
BUFFER
1513

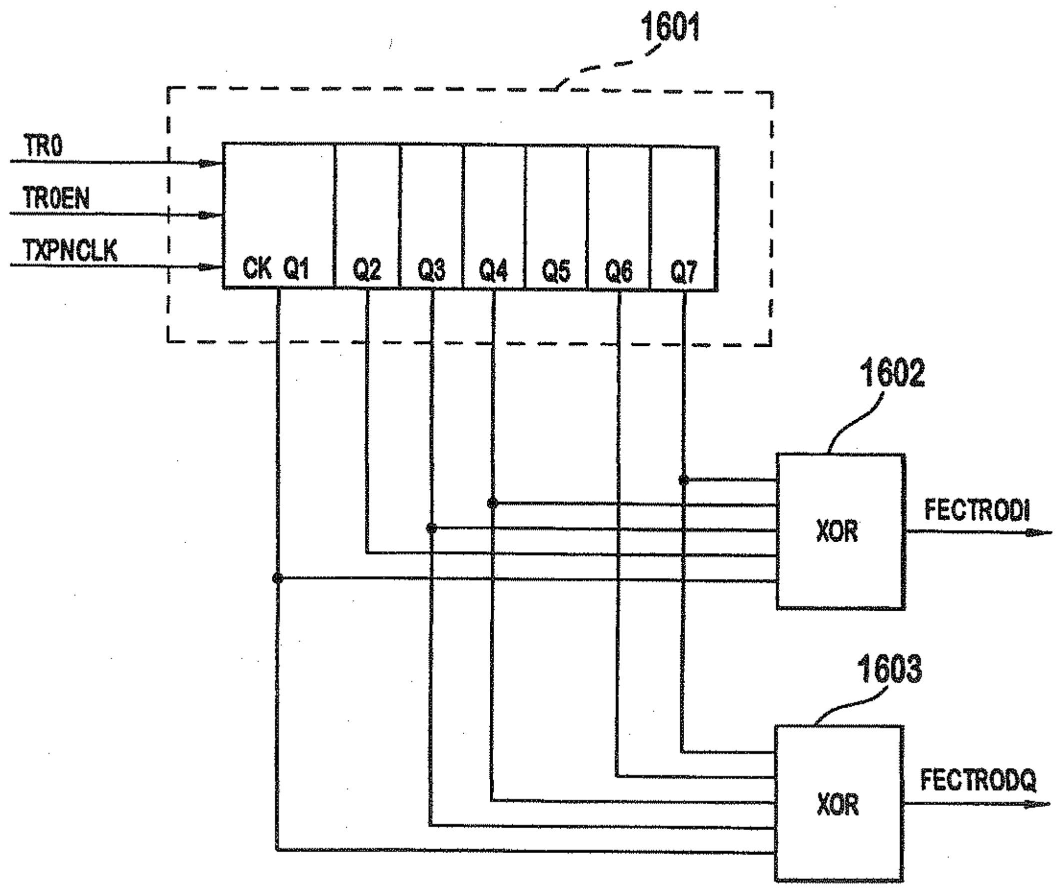
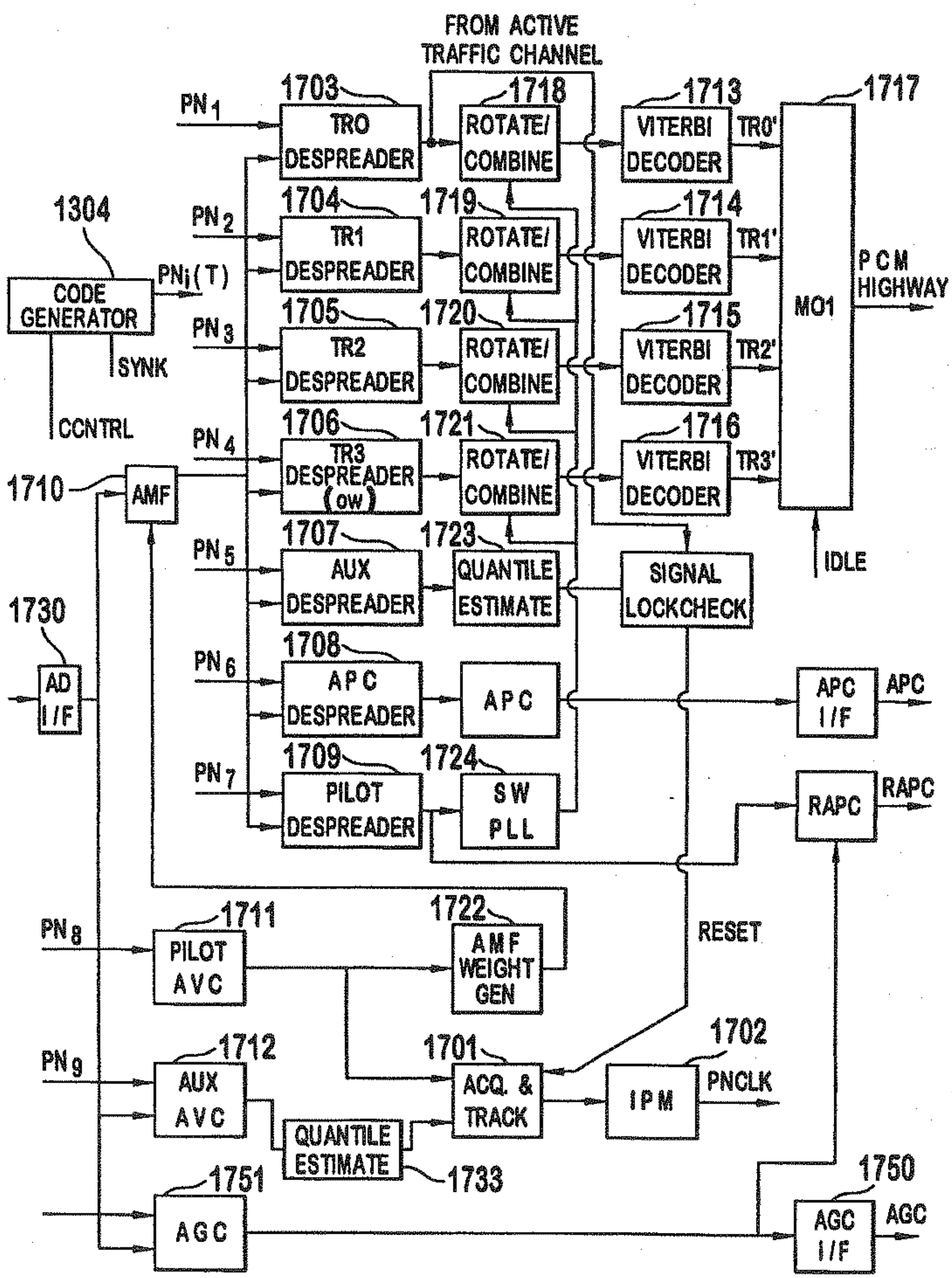

1601
TR0
TR0EN
TXPNCLK
CK Q1
Q2
Q3
Q4
Q5
Q6
Q7
1602
XOR
FECTRODI
1603
XOR
FECTRODQ

FIG. 16



FROM ACTIVE TRAFFIC CHANNEL
1703
TRO DESPREADER
1718
ROTATE/ COMBINE
1713
VITERBI DECODER
TR0'
1717
PN1
1304
PN2
1704
TR1 DESPREADER
1719
ROTATE/ COMBINE
1714
VITERBI DECODER
TR1'
CODE GENERATOR
PNi(T)
SYNK
CCNTRL
PN3
1705
TR2 DESPREADER
1720
ROTATE/ COMBINE
1715
VITERBI DECODER
TR2'
MO1
PCM HIGHWAY
PN4
1706
TR3 DESPREADER (ow)
1721
ROTATE/ COMBINE
1716
VITERBI DECODER
TR3'
1710
AMF
PN5
1707
AUX DESPREADER
1723
QUANTILE ESTIMATE
SIGNAL LOCKCHECK
IDLE
1730
AD I/F
PN6
1708
APC DESPREADER
APC
APC I/F
APC
PN7
1709
PILOT DESPREADER
1724
SW PLL
RAPC
RAPC
RESET
PN8
1711
PILOT AVC
1722
AMF WEIGHT GEN
PN9
1712
AUX AVC
1701
ACQ. & TRACK
IPM
1702
PNCLK
QUANTILE ESTIMATE
1733
1751
AGC
1750
AGC I/F
AGC

FIG. 17

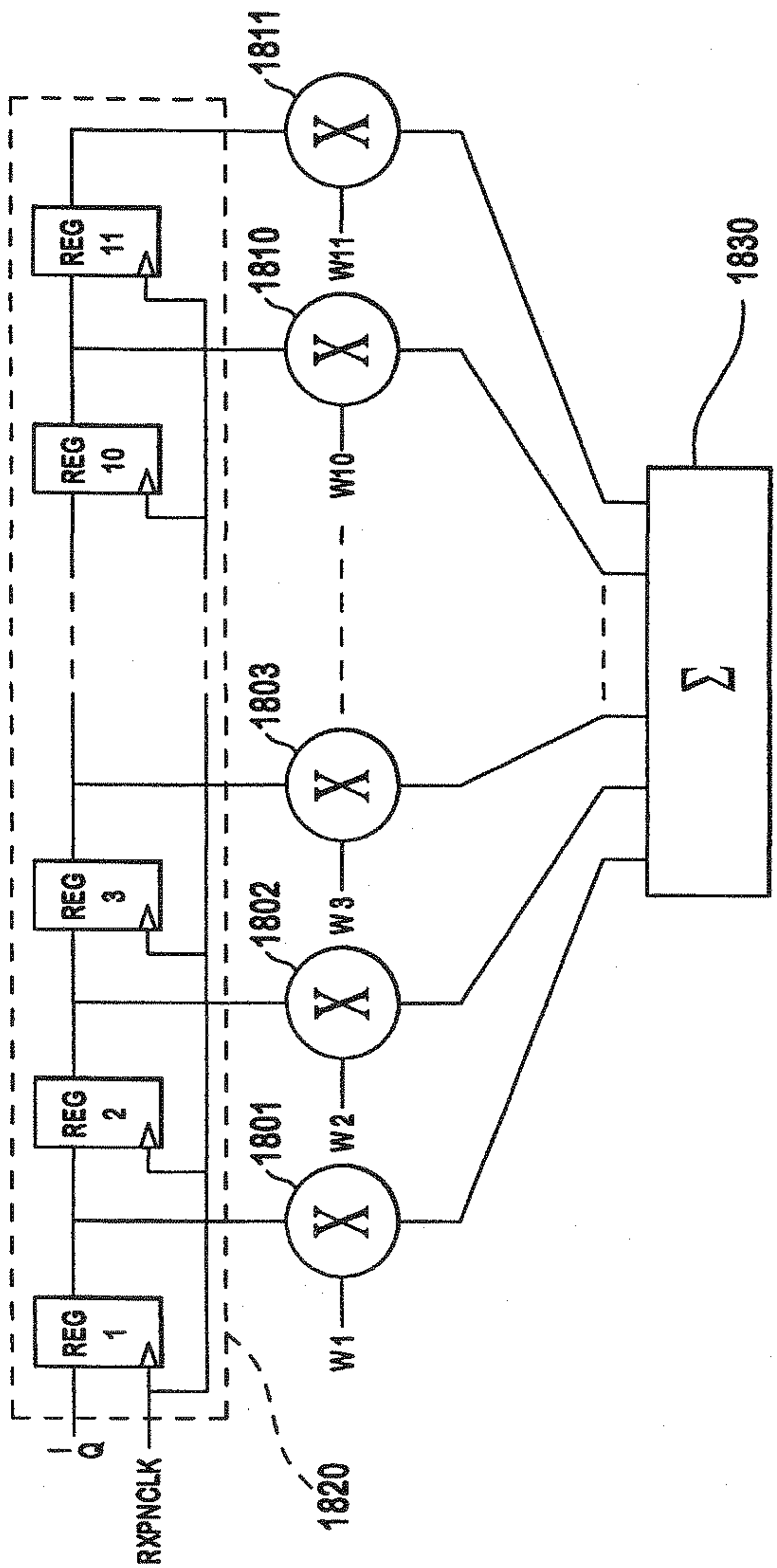

REG 1
REG 2
REG 3
REG 10
REG 11
Q
RXPNCLK
1820
1801
1802
1803
1810
1811
W1
W2
W3
W10
W11
X
X
X
X
X
Σ
1830

FIG. 18

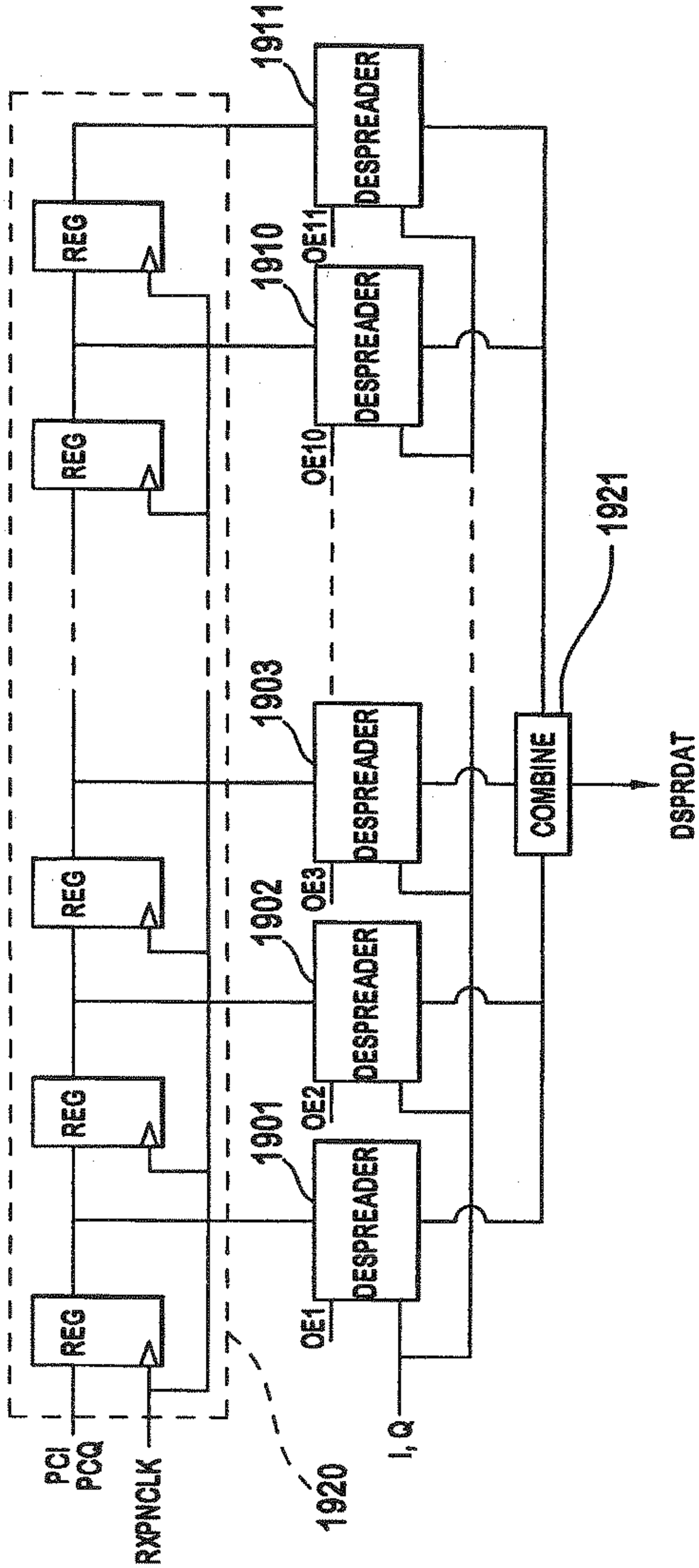

PCI
PCQ
RXPNCLK
1920
REG
REG
REG
REG
REG
1901
1902
1903
1910
1911
DESPREADER
DESPREADER
DESPREADER
DESPREADER
DESPREADER
OE1
OE2
OE3
OE10
OE11
I, Q
COMBINE
1921
DSPRDAT

FIG. 19

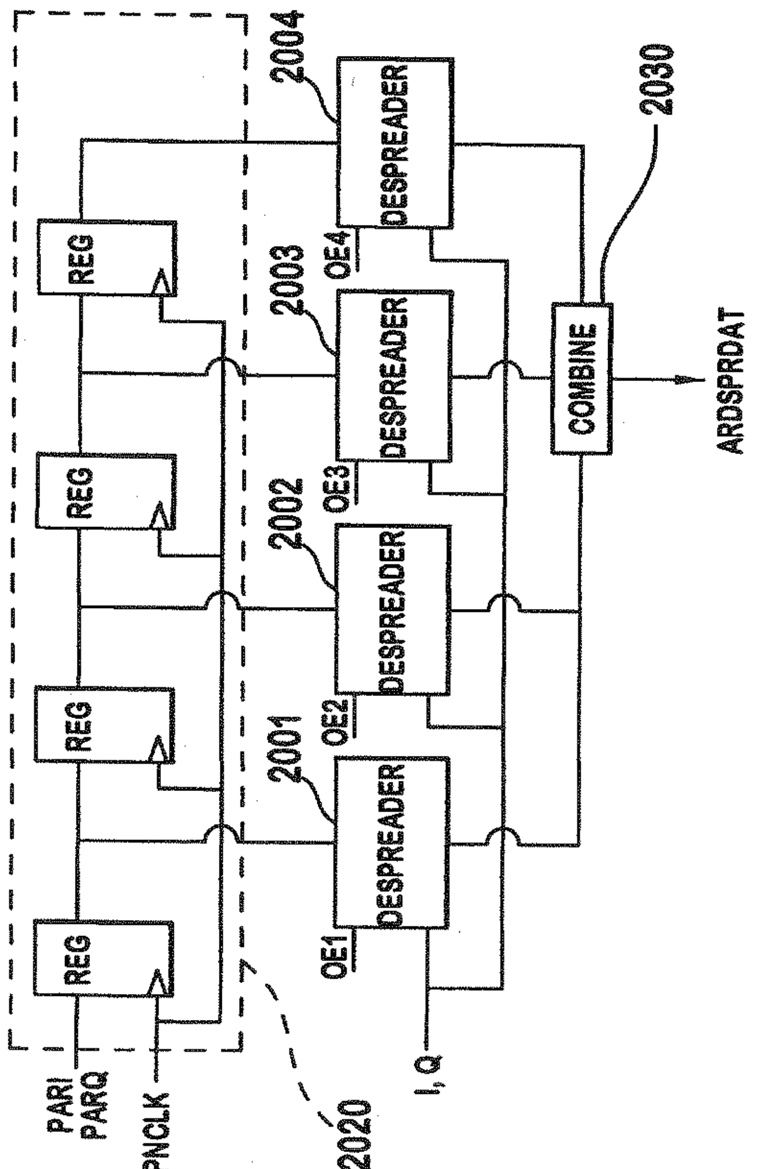
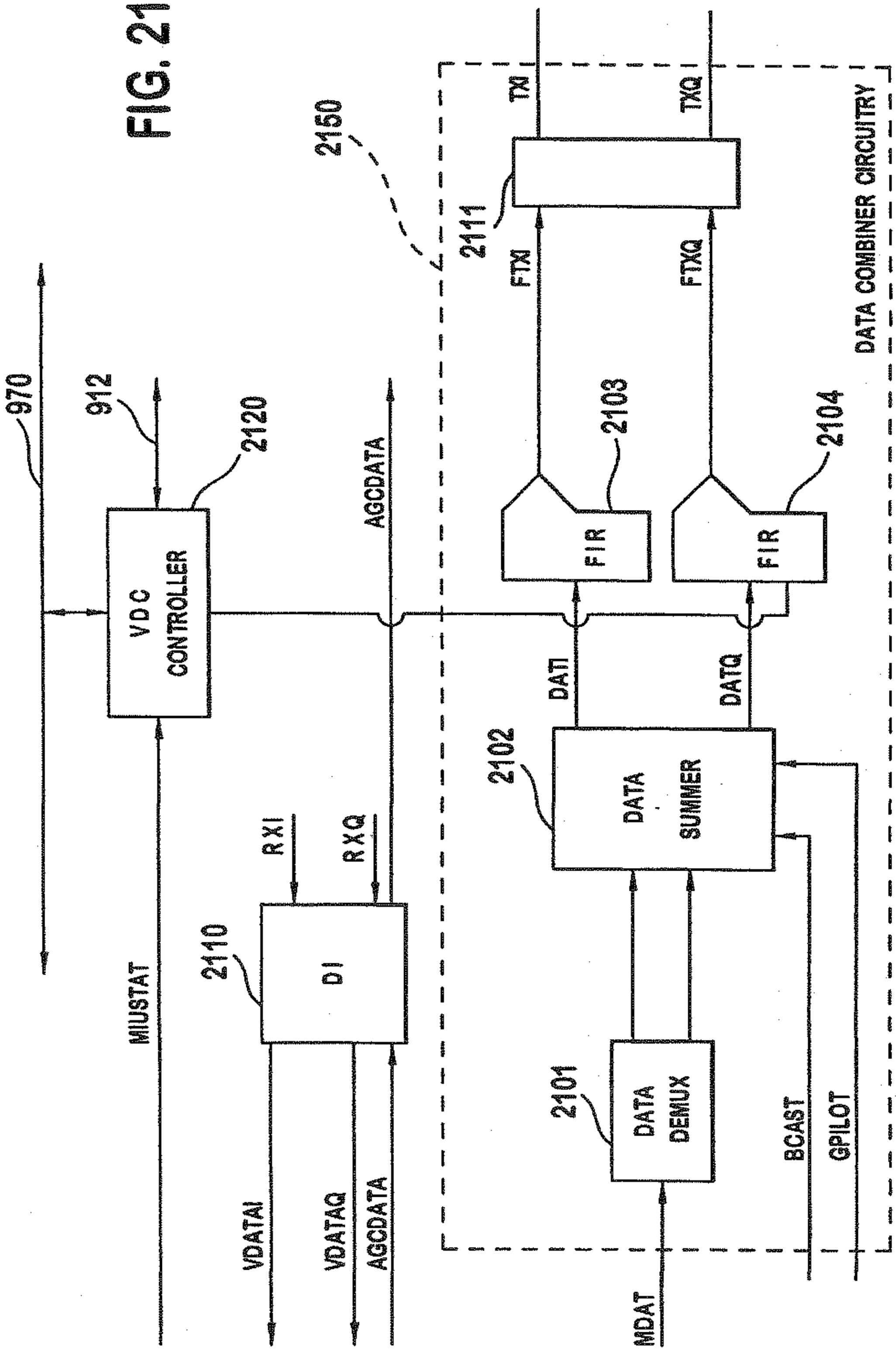

REG
REG
REG
REG
DESPREADER
DESPREADER
DESPREADER
DESPREADER
COMBINE
ARDSPRDAT
OE1
OE2
OE3
OE4
2001
2002
2003
2004
2020
2030
PARI
PARQ
RXPNCLK
I,Q

FIG. 20

FIG. 21


970
912
2120
VDC CONTROLLER
MIUSTAT
AGCDATA
RXI
RXQ
2110
DI
VDATAI
VDATAQ
AGCDATA
2150
2111
TXI
TXQ
FTXI
FTXQ
2103
2104
FIR
FIR
DATI
DATQ
2102
DATA SUMMER
2101
DATA DEMUX
MDAT
BCAST
GPILOT
DATA COMBINER CIRCUITRY

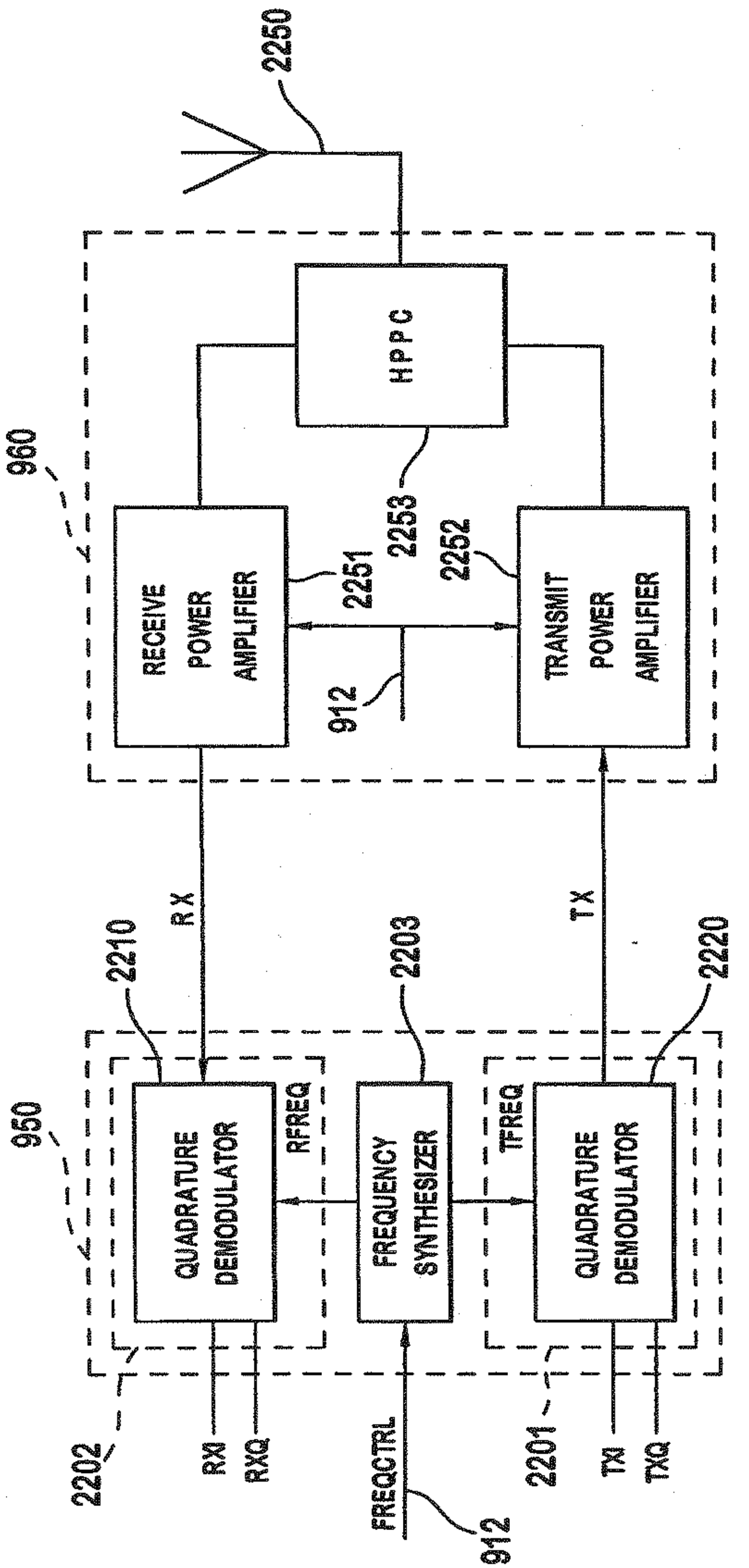

2250
960
HPPC
2253
RECEIVE POWER AMPLIFIER
2251
2252
TRANSMIT POWER AMPLIFIER
912
RX
TX
2210
2203
2220
950
QUADRATURE DEMODULATOR
RFREQ
FREQUENCY SYNTHESIZER
TFREQ
QUADRATURE DEMODULATOR
2202
RXI
RXQ
FREQCTRL
912
2201
TXI
TXQ

FIG. 22

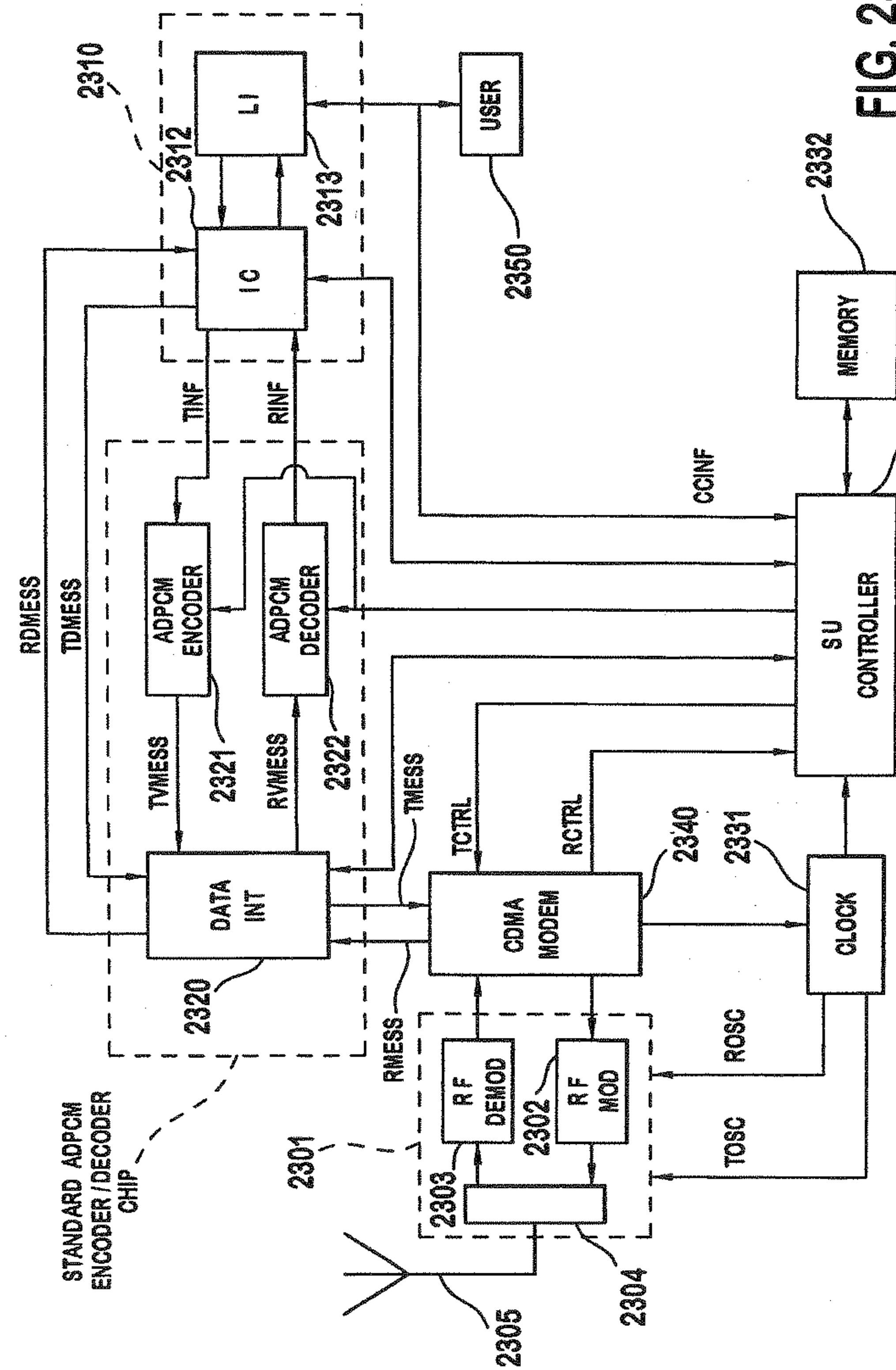

2310
LI
IC
2312
2313
USER
2350
TINF
RINF
ADPCM ENCODER
ADPCM DECODER
RDMESS
TDMESS
TVMESS
2321
RVMESS
2322
TMESS
TCTRL
RCTRL
CCINF
MEMORY
2332
2330
SU CONTROLLER
DATA INT
2320
CDMA MODEM
2340
2331
CLOCK
RMESS
R F DEMOD
R F MOD
2302
2301
2303
2304
2305
ROSC
TOSC
STANDARD ADPCM ENCODER / DECODER CHIP

FIG. 23

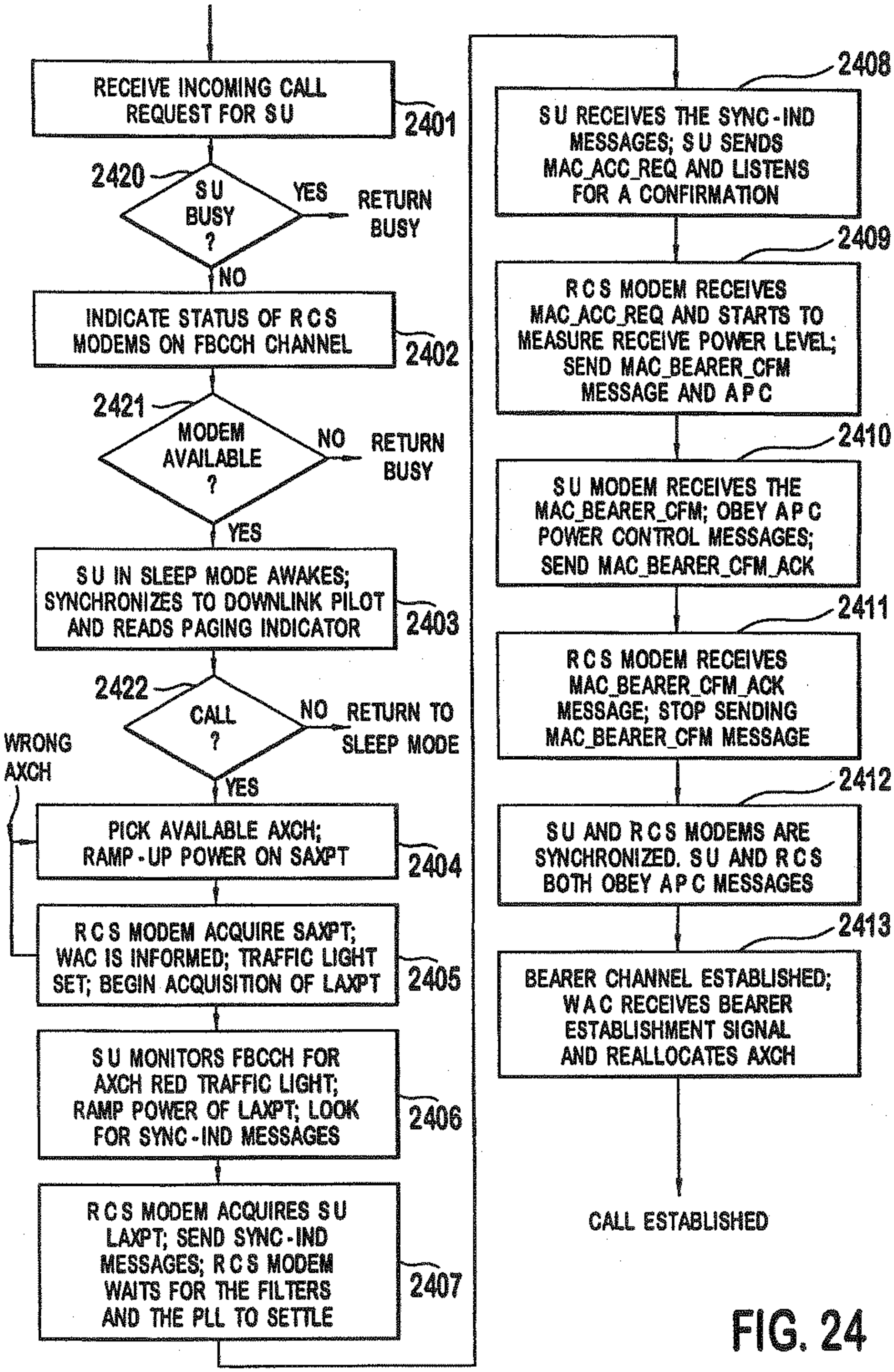
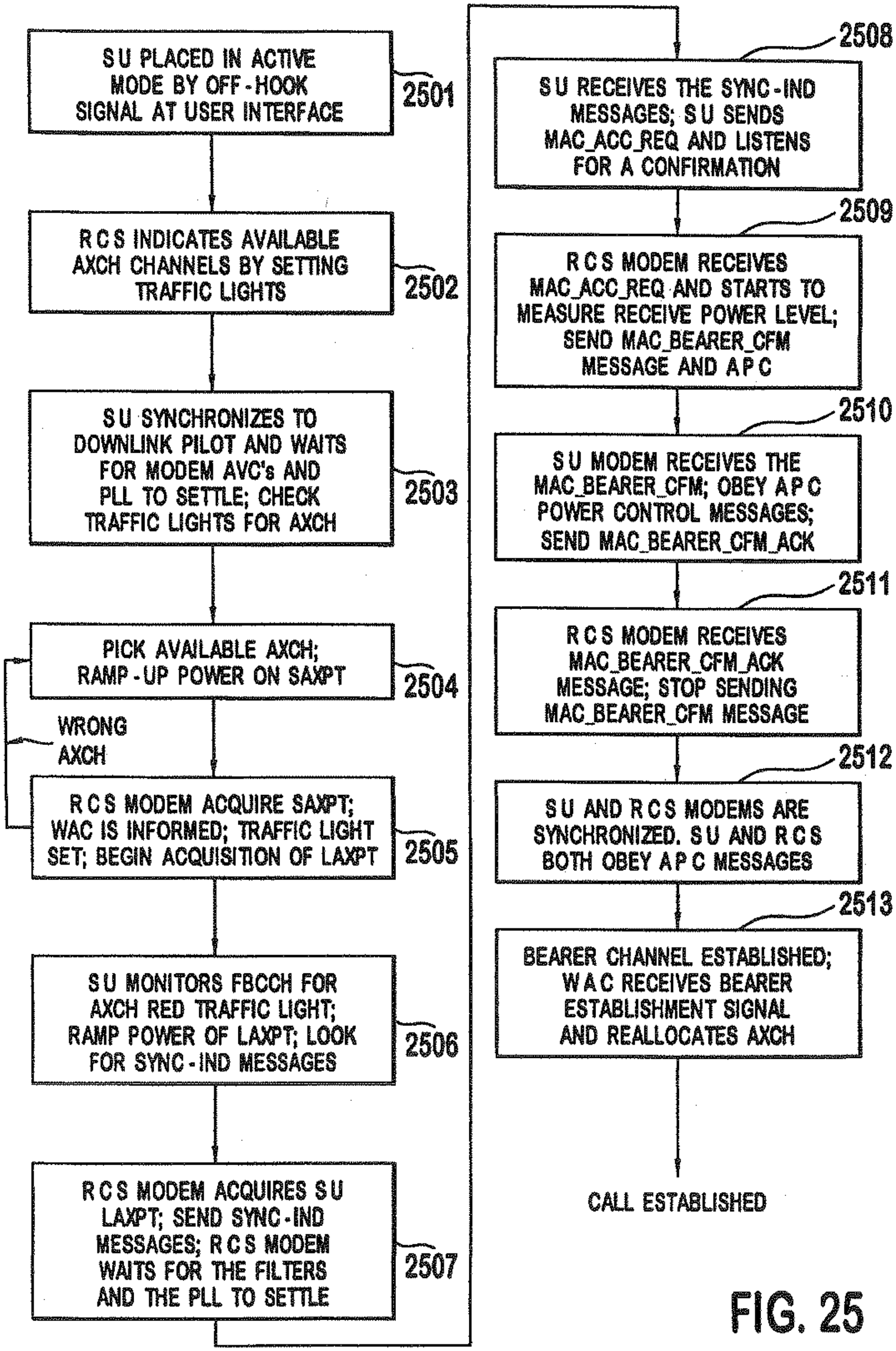
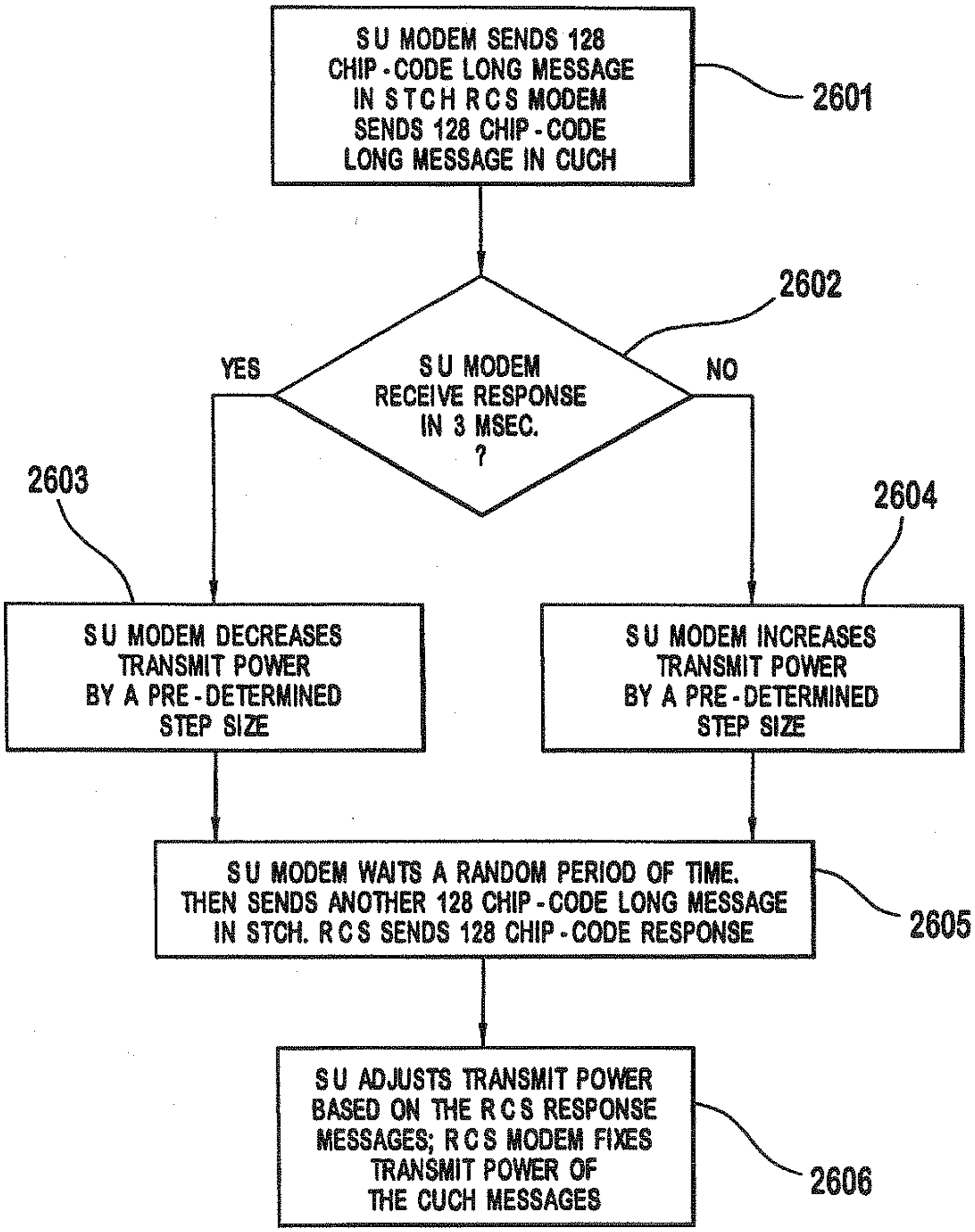

RECEIVE INCOMING CALL REQUEST FOR S U
2401
2420
S U BUSY ?
YES
RETURN BUSY
NO
INDICATE STATUS OF R C S MODEMS ON FBCCH CHANNEL
2402
2421
MODEM AVAILABLE ?
NO
RETURN BUSY
YES
S U IN SLEEP MODE AWAKES; SYNCHRONIZES TO DOWNLINK PILOT AND READS PAGING INDICATOR
2403
2422
CALL ?
NO
RETURN TO SLEEP MODE
YES
WRONG AXCH
PICK AVAILABLE AXCH; RAMP-UP POWER ON SAXPT
2404
R C S MODEM ACQUIRE SAXPT; WAC IS INFORMED; TRAFFIC LIGHT SET; BEGIN ACQUISITION OF LAXPT
2405
S U MONITORS FBCCH FOR AXCH RED TRAFFIC LIGHT; RAMP POWER OF LAXPT; LOOK FOR SYNC-IND MESSAGES
2406
R C S MODEM ACQUIRES S U LAXPT; SEND SYNC-IND MESSAGES; R C S MODEM WAITS FOR THE FILTERS AND THE PLL TO SETTLE
2407
2408
S U RECEIVES THE SYNC-IND MESSAGES; S U SENDS MAC_ACC_REQ AND LISTENS FOR A CONFIRMATION
2409
R C S MODEM RECEIVES MAC_ACC_REQ AND STARTS TO MEASURE RECEIVE POWER LEVEL; SEND MAC_BEARER_CFM MESSAGE AND A P C
2410
S U MODEM RECEIVES THE MAC_BEARER_CFM; OBEY A P C POWER CONTROL MESSAGES; SEND MAC_BEARER_CFM_ACK
2411
R C S MODEM RECEIVES MAC_BEARER_CFM_ACK MESSAGE; STOP SENDING MAC_BEARER_CFM MESSAGE
2412
S U AND R C S MODEMS ARE SYNCHRONIZED. S U AND R C S BOTH OBEY A P C MESSAGES
2413
BEARER CHANNEL ESTABLISHED; W A C RECEIVES BEARER ESTABLISHMENT SIGNAL AND REALLOCATES AXCH
CALL ESTABLISHED

FIG. 24



S U PLACED IN ACTIVE MODE BY OFF-HOOK SIGNAL AT USER INTERFACE
2501
R C S INDICATES AVAILABLE AXCH CHANNELS BY SETTING TRAFFIC LIGHTS
2502
S U SYNCHRONIZES TO DOWNLINK PILOT AND WAITS FOR MODEM AVC's AND PLL TO SETTLE; CHECK TRAFFIC LIGHTS FOR AXCH
2503
PICK AVAILABLE AXCH; RAMP-UP POWER ON SAXPT
2504
WRONG AXCH
R C S MODEM ACQUIRE SAXPT; WAC IS INFORMED; TRAFFIC LIGHT SET; BEGIN ACQUISITION OF LAXPT
2505
S U MONITORS FBCCH FOR AXCH RED TRAFFIC LIGHT; RAMP POWER OF LAXPT; LOOK FOR SYNC-IND MESSAGES
2506
R C S MODEM ACQUIRES S U LAXPT; SEND SYNC-IND MESSAGES; R C S MODEM WAITS FOR THE FILTERS AND THE PLL TO SETTLE
2507
2508
S U RECEIVES THE SYNC-IND MESSAGES; S U SENDS MAC_ACC_REQ AND LISTENS FOR A CONFIRMATION
2509
R C S MODEM RECEIVES MAC_ACC_REQ AND STARTS TO MEASURE RECEIVE POWER LEVEL; SEND MAC_BEARER_CFM MESSAGE AND A P C
2510
S U MODEM RECEIVES THE MAC_BEARER_CFM; OBEY A P C POWER CONTROL MESSAGES; SEND MAC_BEARER_CFM_ACK
2511
R C S MODEM RECEIVES MAC_BEARER_CFM_ACK MESSAGE; STOP SENDING MAC_BEARER_CFM MESSAGE
2512
S U AND R C S MODEMS ARE SYNCHRONIZED. S U AND R C S BOTH OBEY A P C MESSAGES
2513
BEARER CHANNEL ESTABLISHED; W A C RECEIVES BEARER ESTABLISHMENT SIGNAL AND REALLOCATES AXCH
CALL ESTABLISHED

FIG. 25



SU MODEM SENDS 128 CHIP-CODE LONG MESSAGE IN STCH RCS MODEM SENDS 128 CHIP-CODE LONG MESSAGE IN CUCH
2601
2602
SU MODEM RECEIVE RESPONSE IN 3 MSEC. ?
YES
NO
2603
2604
SU MODEM DECREASES TRANSMIT POWER BY A PRE-DETERMINED STEP SIZE
SU MODEM INCREASES TRANSMIT POWER BY A PRE-DETERMINED STEP SIZE
SU MODEM WAITS A RANDOM PERIOD OF TIME. THEN SENDS ANOTHER 128 CHIP-CODE LONG MESSAGE IN STCH. RCS SENDS 128 CHIP-CODE RESPONSE
2605
SU ADJUSTS TRANSMIT POWER BASED ON THE RCS RESPONSE MESSAGES; RCS MODEM FIXES TRANSMIT POWER OF THE CUCH MESSAGES
2606

FIG. 26

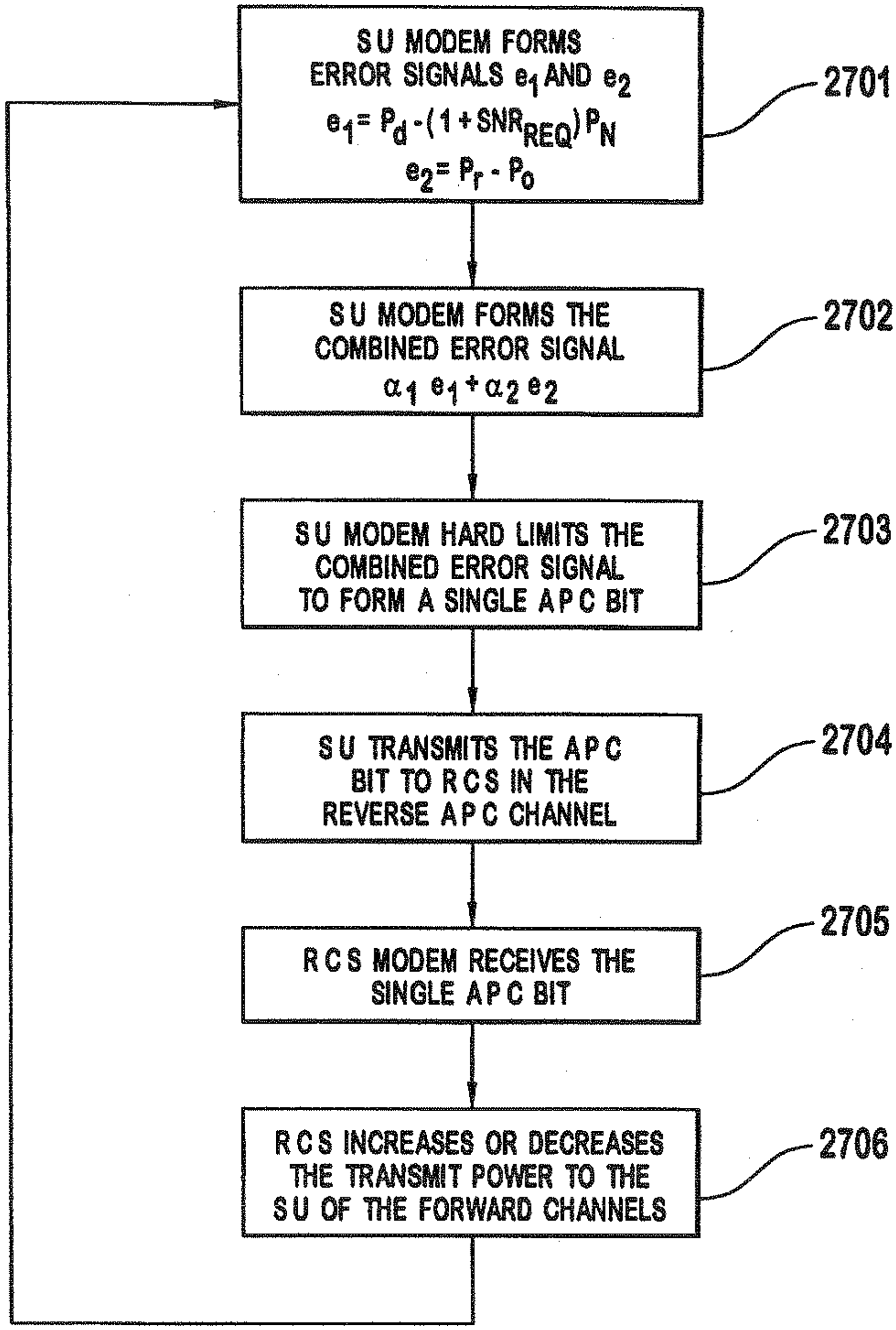

S U MODEM FORMS ERROR SIGNALS e_1 AND e_2
$e_1 = P_d - (1 + SNR_{REQ}) P_N$
$e_2 = P_r - P_o$
2701
S U MODEM FORMS THE COMBINED ERROR SIGNAL $\alpha_1 e_1 + \alpha_2 e_2$
2702
S U MODEM HARD LIMITS THE COMBINED ERROR SIGNAL TO FORM A SINGLE A P C BIT
2703
S U TRANSMITS THE A P C BIT TO R C S IN THE REVERSE A P C CHANNEL
2704
R C S MODEM RECEIVES THE SINGLE A P C BIT
2705
R C S INCREASES OR DECREASES THE TRANSMIT POWER TO THE S U OF THE FORWARD CHANNELS
2706

FIG. 27

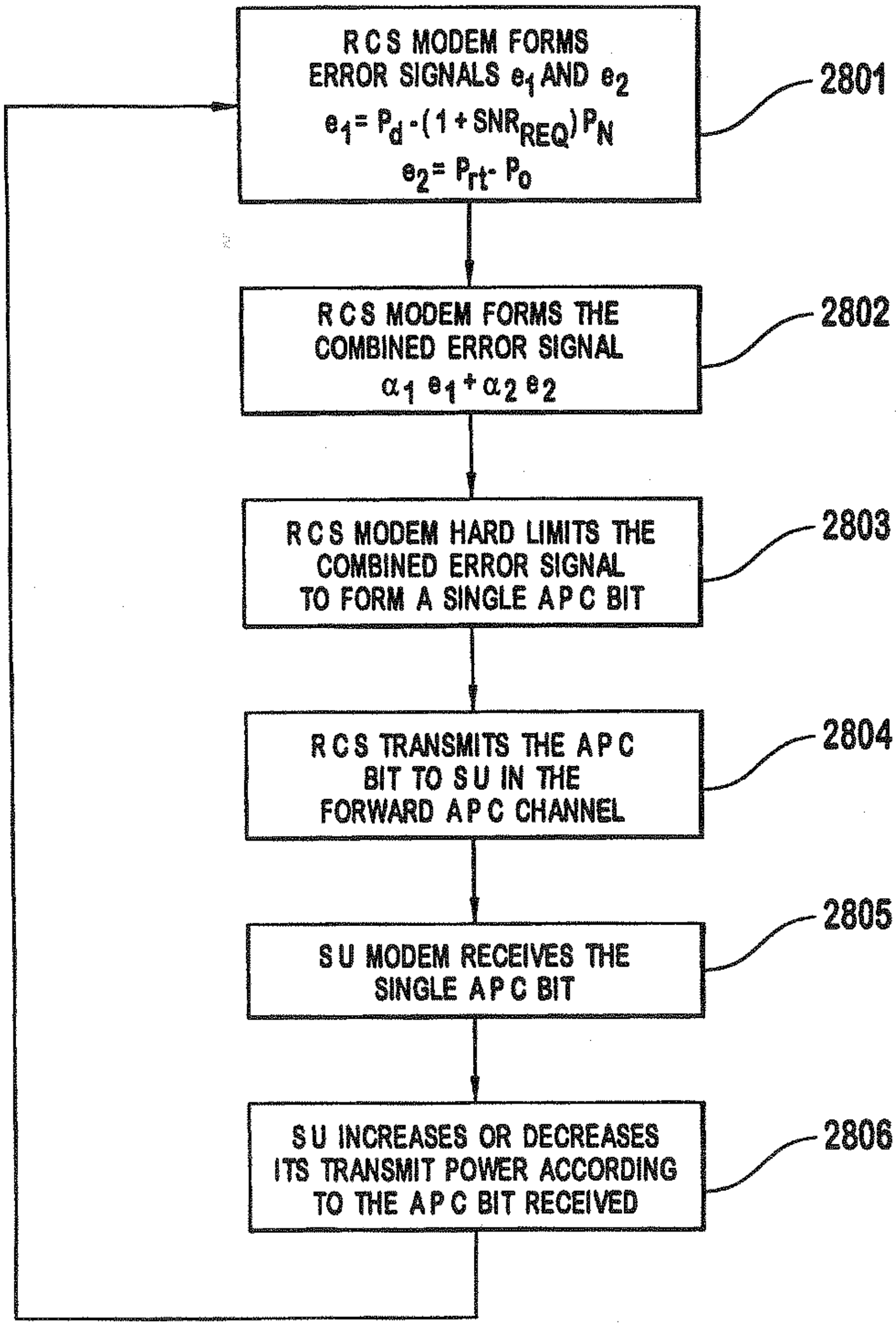

RCS MODEM FORMS ERROR SIGNALS e_1 AND e_2
$e_1 = P_d - (1 + SNR_{REQ}) P_N$
$e_2 = P_{rt} - P_o$
2801
RCS MODEM FORMS THE COMBINED ERROR SIGNAL $\alpha_1 e_1 + \alpha_2 e_2$
2802
RCS MODEM HARD LIMITS THE COMBINED ERROR SIGNAL TO FORM A SINGLE APC BIT
2803
RCS TRANSMITS THE APC BIT TO SU IN THE FORWARD APC CHANNEL
2804
SU MODEM RECEIVES THE SINGLE APC BIT
2805
SU INCREASES OR DECREASES ITS TRANSMIT POWER ACCORDING TO THE APC BIT RECEIVED
2806

FIG. 28

FIG. 29A

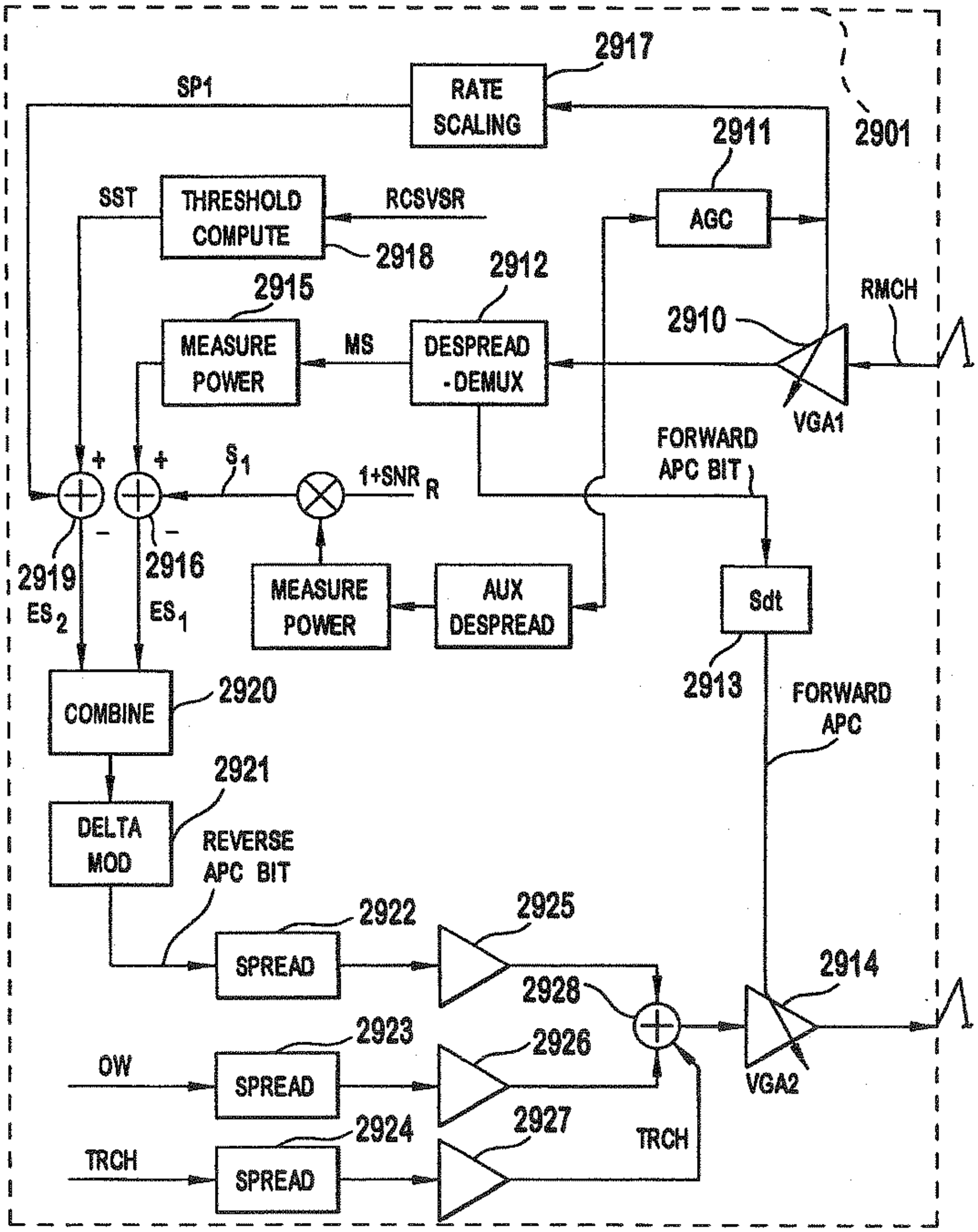

2917
RATE SCALING
SP1
2901
2911
AGC
SST
THRESHOLD COMPUTE
RCSVSR
2918
2912
2915
RMCH
2910
MEASURE POWER
MS
DESPREAD -DEMUX
VGA1
FORWARD APC BIT
+
+
S_1
1+SNR R
-
-
2919
2916
ES_2
ES_1
MEASURE POWER
AUX DESPREAD
Sdt
2913
FORWARD APC
COMBINE
2920
2921
DELTA MOD
REVERSE APC BIT
2922
2925
SPREAD
2928
2914
2923
2926
OW
SPREAD
VGA2
2924
2927
TRCH
TRCH
SPREAD

FIG. 29B

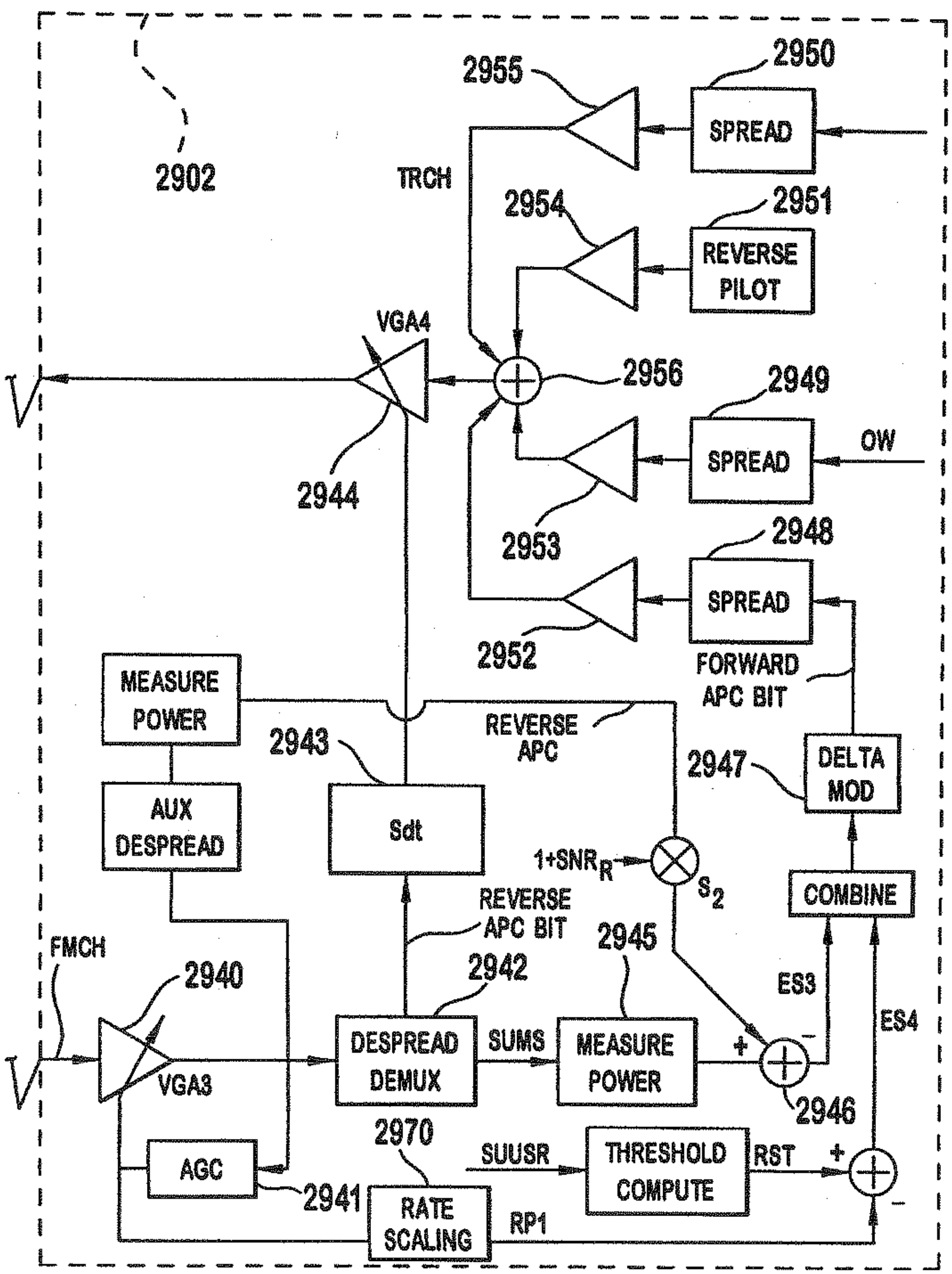
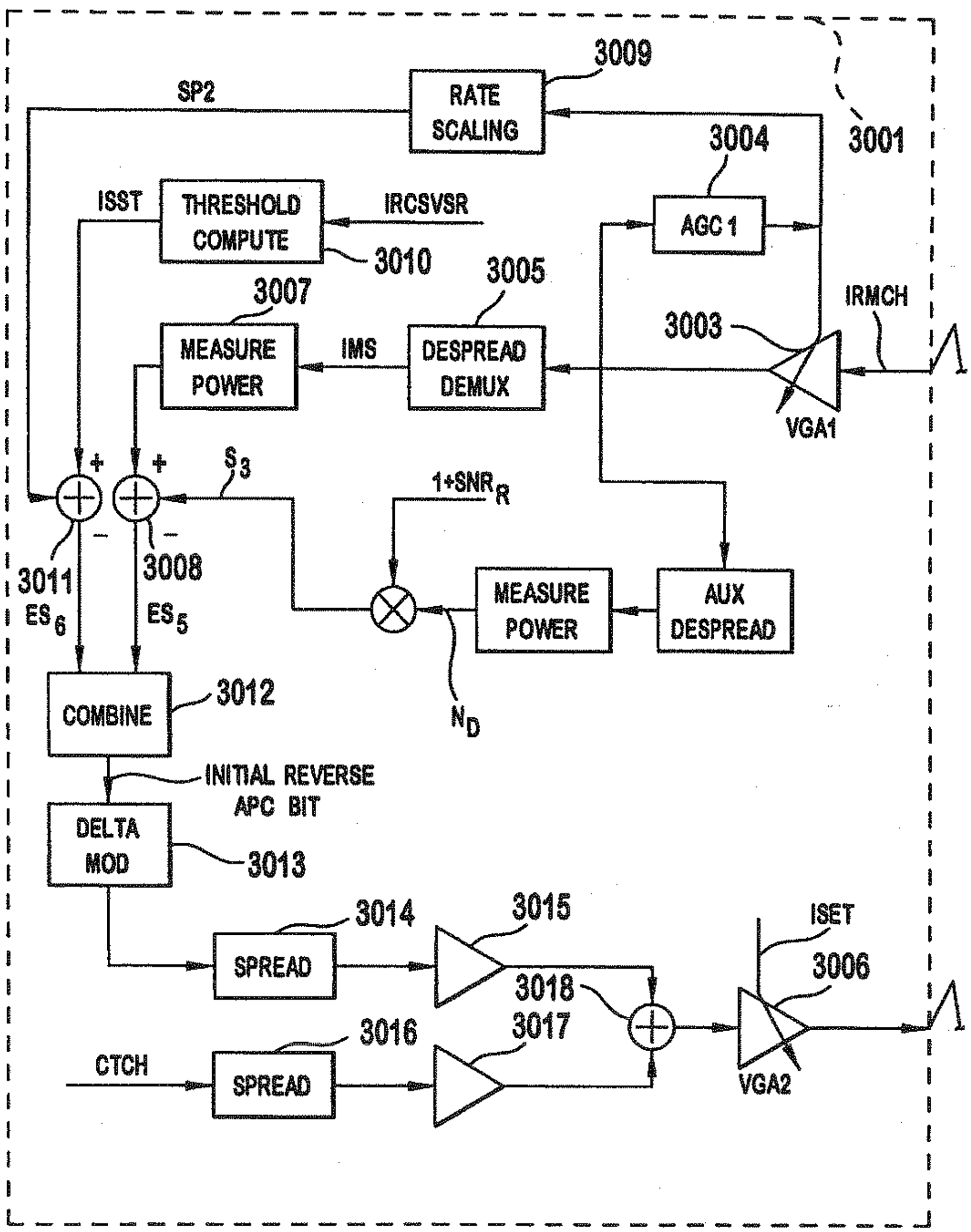
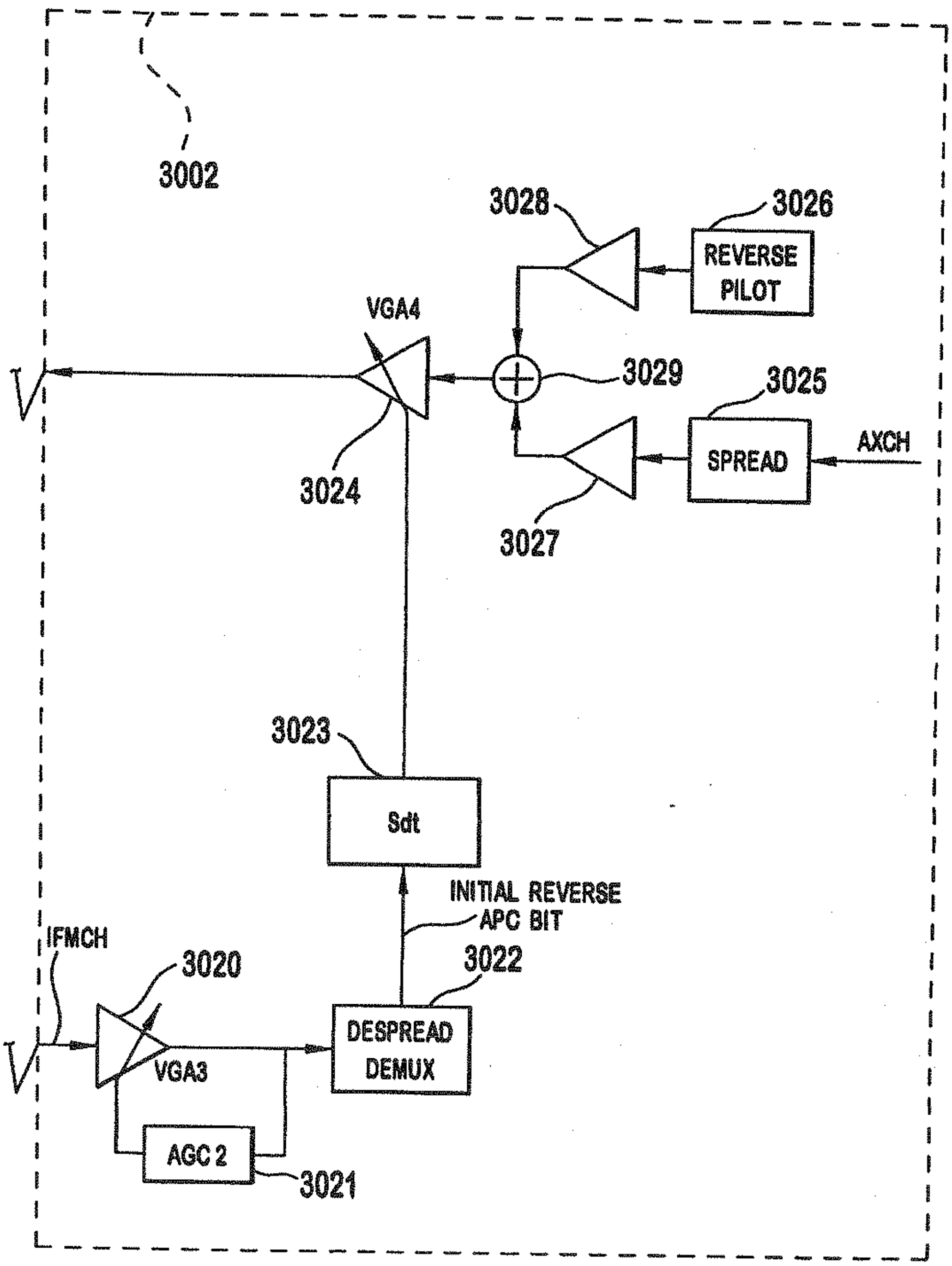

2902
2955
2950
SPREAD
TRCH
2954
2951
REVERSE PILOT
VGA4
2956
2949
SPREAD
OW
2944
2953
2948
SPREAD
2952
FORWARD APC BIT
MEASURE POWER
2943
REVERSE APC
2947
DELTA MOD
AUX DESPREAD
Sdt
1+SNR
R
S
2
COMBINE
REVERSE APC BIT
2945
FMCH
2940
2942
ES3
ES4
DESPREAD DEMUX
SUMS
MEASURE POWER
+
-
VGA3
2946
2970
SUUSR
THRESHOLD COMPUTE
RST
+
AGC
2941
RATE SCALING
RP1
-

FIG. 30A



3009
RATE SCALING
SP2
3004
3001
ISST
THRESHOLD COMPUTE
IRCSVSR
AGC 1
3010
3005
3007
IRMCH
3003
MEASURE POWER
IMS
DESPREAD DEMUX
VGA1
+
+
S3
1+SNRR
3011
3008
ES6
ES5
MEASURE POWER
AUX DESPREAD
COMBINE
3012
ND
INITIAL REVERSE APC BIT
DELTA MOD
3013
3014
3015
ISET
SPREAD
3018
3006
3016
3017
CTCH
SPREAD
VGA2

FIG. 30B


3002
3028
3026
REVERSE PILOT
VGA4
3029
3025
SPREAD
AXCH
3024
3027
3023
Sdt
INITIAL REVERSE APC BIT
3022
IFMCH
3020
DESPREAD DEMUX
VGA3
AGC 2
3021

BEARER CHANNEL MODIFICATION SYSTEM FOR A CODE DIVISION MULTIPLE ACCESS (CDMA) COMMUNICATION SYSTEM

This application is a division of application Ser. No. 08/669,775, filed Jun. 27, 1996, now U.S. Pat. No. 5,799,010.

This application claims the benefit of U.S. Provisional Application Ser. No. 60/000,775 filed Jun. 30, 1995.

BACKGROUND OF THE INVENTION

The present invention generally pertains to Code Division Multiple Access (CDMA) communications, also known as spread-spectrum communications. More particularly, the present invention pertains to a system and method for providing a high capacity, CDMA communications system which provides for one or more simultaneous user bearer channels over a given radio frequency, allowing dynamic allocation of bearer channel rate while rejecting multipath interference.

DESCRIPTION OF THE RELEVANT ART

Providing quality telecommunication services to user groups which are classified as remote, such as rural telephone systems and telephone systems in underdeveloped countries, has proved to be a challenge in recent years. These needs have been partially satisfied by wireless radio services, such as fixed or mobile frequency division multiplex (FDM), frequency division multiple access (FDMA), time division multiplex (TDM), time division multiple access (TDMA) systems, combination frequency and time division systems (FD/TDMA), and other land mobile radio systems. Usually, these remote services are faced with more potential users than can be supported simultaneously by their frequency or spectral bandwidth capacity.

Recognizing these limitations, recent advances in wireless communications have used spread spectrum modulation techniques to provide simultaneous communication by multiple users. Spread spectrum modulation refers to modulating a information signal with a spreading code signal; the spreading code signal being generated by a code generator where the period Tc of the spreading code is substantially less than the period of the information data bit or symbol signal. The code may modulate the carrier frequency upon which the information has been sent, called frequency-hopped spreading, or may directly modulate the signal by multiplying the spreading code with the information data signal, called direct-sequence spreading (DS). Spread-spectrum modulation produces a signal with bandwidth substantially greater than that required to transmit the information signal. Synchronous reception and despreading of the signal at the receiver recovers the original information. A synchronous demodulator in the receiver uses a reference signal to synchronize the despreading circuits to the input spread-spectrum modulated signal to recover the carrier and information signals. The reference signal can be a spreading code which is not modulated by an information signal. Such use of a synchronous spread-spectrum modulation and demodulation for wireless communication is described in U.S. Pat. No. 5,228,056 entitled SYNCHRONOUS SPREAD-SPECTRUM COMMUNICATIONS SYSTEM AND METHOD by Donald L. Schilling, which techniques are incorporated herein by reference.

Spread-spectrum modulation in wireless networks offers many advantages because multiple users may use the same

frequency band with minimal interference to each user's receiver. Spread-spectrum modulation also reduces effects from other sources of interference. In addition, synchronous spread-spectrum modulation and demodulation techniques may be expanded by providing multiple message channels for a single user, each spread with a different spreading code, while still transmitting only a single reference signal to the user. Such use of multiple message channels modulated by a family of spreading codes synchronized to a pilot spreading code for wireless communication is described in U.S. Pat. No. 5,166,951 entitled HIGH CAPACITY SPREAD-SPECTRUM CHANNEL by Donald L. Schilling, which is incorporated herein by reference.

One area in which spread-spectrum techniques are used is in the field of mobile cellular communications to provide personal communication services (PCS). Such systems desirably support large numbers of users, control Doppler shift and fade, and provide high speed digital data signals with low bit error rates. These systems employ a family of orthogonal or quasi-orthogonal spreading codes, with a pilot spreading code sequence synchronized to the family of codes. Each user is assigned one of the spreading codes as a spreading function. Related problems of such a system are: supporting a large number of users with the orthogonal codes, handling reduced power available to remote units,- and handling multipath fading effects. Solutions to such problems include using phased-array antennas to generate multiple steerable beams, using very long orthogonal or quasi-orthogonal code sequences. These sequences may be reused by cyclic shifting of the code synchronized to a central reference, and diversity combining of multipath signals. Such problems associated with spread spectrum communications, and methods to increase capacity of a multiple access, spread-spectrum system are described in U.S. Pat. No. 4,901,307 entitled SPREAD SPECTRUM MULTIPLE ACCESS COMMUNICATION SYSTEM USING SATELLITE OR TERRESTRIAL REPEATERS by Gilhousen et al. which is incorporated herein by reference.

The problems associated with the prior art systems focus around reliable reception and synchronization of the receiver despreading circuits to the received signal. The presence of multipath fading introduces a particular problem with spread spectrum receivers in that a receiver must somehow track the multipath components to maintain code-phase lock of the receiver's despreading means with the input signal. Prior art receivers generally track only one or two of the multipath signals, but this method is not satisfactory because the combined group of low power multipath signal components may actually contain far more power than the one or two strongest multipath components. The prior art receivers track and combine the strongest components to maintain a predetermined Bit Error Rate (BER) of the receiver. Such a receiver is described, for example, in U.S. Pat. No. 5,109,390 entitled DIVERSITY RECEIVER IN A CDMA CELLULAR TELEPHONE SYSTEM by Gilhousen et al. A receiver that combines all multipath components, however, is able to maintain the desired BER with a signal power that is lower than that of prior art systems because more signal power is available to the receiver. Consequently, there is a need for a spread spectrum communication system employing a receiver that tracks substantially all of the multipath signal components, so that substantially all multipath signals may be combined in the receiver, and hence the required transmit power of the signal for a given BER may be reduced.

Another problem associated with multiple access, spread-spectrum communication systems is the need to reduce the

total transmitted power of users in the system, since users may have limited available power. An associated problem requiring power control in spread-spectrum systems is related to the inherent characteristic of spread-spectrum systems that one user's spread-spectrum signal is received by another user's receiver as noise with a certain power level. Consequently, users transmitting with high levels of signal power may interfere with other users' reception. Also, if a user moves relative to another user's geographic location, signal fading and distortion require that the users adjust their transmit power level to maintain a particular signal quality. At the same time, the system should keep the power that the base station receives from all users relatively constant. Finally, because it is possible for the spread-spectrum system to have more remote users than can be supported simultaneously, the power control system should also employ a capacity management method which rejects additional users when the maximum system power level is reached.

Prior spread-spectrum systems have employed a base station that measures a received signal and sends an adaptive power control (APC) signal to the remote users. Remote users include a transmitter with an automatic gain control (AGC) circuit which responds to the APC signal. In such systems the base station monitors the overall system power or the power received from each user, and sets the APC signal accordingly. Such a spread-spectrum power control system and method is described in U.S. Pat. No. 5,299,226 entitled ADAPTIVE POWER CONTROL FOR A SPREAD SPECTRUM COMMUNICATION SYSTEM AND METHOD, and U.S. Pat. No. 5,093,840 entitled ADAPTIVE POWER CONTROL FOR A SPREAD SPECTRUM TRANSMITTER, both by Donald L. Schilling and incorporated herein by reference. This open loop system performance may be improved by including a measurement of the signal power received by the remote user from the base station, and transmitting an APC signal back to the base station to effectuate a closed loop power control method. Such closed loop power control is described, for example, in U.S. Pat. No. 5,107,225 entitled HIGH DYNAMIC RANGE CLOSED LOOP AUTOMATIC GAIN CONTROL CIRCUIT to Charles E. Wheatley, III et al. and incorporated herein by reference.

These power control systems, however, exhibit several disadvantages. First, the base station must perform complex power control algorithms, increasing the amount of processing in the base station. Second, the system actually experiences several types of power variation: variation in the noise power caused by the variation in the number of users and variations in the received signal power of a particular bearer channel. These variations occur with different frequency, so simple power control algorithms can be optimized to compensate for only one of the two types of variation. Finally, these power algorithms tend to drive the overall system power to a relatively high level. Consequently, there is a need for a spread-spectrum power control method that rapidly responds to changes in bearer channel power levels, while simultaneously making adjustments to all users' transmit power in response to changes in the number of users. Also, there is a need for an improved spread-spectrum communication system employing a closed loop power control system which minimizes the system's overall power requirements while maintaining a sufficient BER at the individual remote receivers. In addition, such a system should control the initial transmit power level of a remote user and manage total system capacity.

Spread-spectrum communication systems desirably should support large numbers of users, each of which has at least one communication channel. In addition, such a system should provide multiple generic information channels to broadcast information to all users and to enable users to gain access to the system. Using prior art spread-spectrum systems this could only be accomplished by generating large numbers of spreading code sequences.

Further, spread-spectrum systems should use sequences that are orthogonal or nearly orthogonal to reduce the probability that a receiver locks to the wrong spreading code sequence or phase. The use of such orthogonal codes and the benefits arising therefrom are outlined in U.S. Pat. No. 5,103,459 entitled SYSTEM AND METHOD FOR GENERATING SIGNAL WAVEFORMS IN A CDMA CELLULAR TELEPHONE SYSTEM, by Gilhousen et al. and U.S. Pat. No. 5,193,094 entitled METHOD AND APPARATUS FOR GENERATING SUPER-ORTHOGONAL CONVOLUTIONAL CODES AND THE DECODING THEREOF, by Andrew J. Viterbi, both of which are incorporated herein by reference. However, generating such large families of code sequences with such properties is difficult. Also, generating large code families requires generating sequences which have a long period before repetition- Consequently, the time a receiver takes to achieve synchronization with such a long sequence is increased. Prior art spreading code generators often combine shorter sequences to make longer sequences, but such sequences may no longer be sufficiently orthogonal. Therefore, there is a need for an improved method for reliably generating large families of code sequences that exhibit nearly orthogonal characteristics and have a long period before repetition, but also include the benefit of a short code sequence that reduces the time to acquire and lock the receiver to the correct code phase. In addition, the code generation method should allow generation of codes with any period, since the spreading code period is often determined by parameters used such as data rate or frame size.

Another desirable characteristic of spreading code sequences is that the transition of the user data value occur at a transition of the code sequence values. Since data typically has a period which is divisible by 2^N, such a characteristic usually requires the code-sequence to be an even length of 2^N. However, code generators, as is well known in the art, generally use linear feedback shift registers which generate codes of length 2^N-1. Some generators include a method to augment the generated code sequence by inserting an additional code value, as described, for example, in U.S. Pat. No. 5,228,054 entitled POWER-OF-TWO LENGTH PSEUDONOISE SEQUENCE GENERATOR WITH FAST OFFSET ADJUSTMENT by Timothy Rueth et al and incorporated herein by reference. Consequently, the spread-spectrum communication system should also generate spreading code sequences of even length.

Finally, the spread-spectrum communication system should be able to handle many different types of data, such as FAX, voiceband data, and ISDN, in addition to traditional voice traffic. To increase the number of users supported, many systems employ encoding techniques such as ADPCM to achieve "compression" of the digital telephone signal. FAX, ISDN and other data, however, require the channel to be a clear channel. Consequently, there is a need for a spread spectrum communication system that supports compression techniques that also dynamically modify the spread spectrum bearer channel between an encoded channel and a clear channel in response to the type of information contained in the user's signal.

SUMMARY OF THE INVENTION

The present invention is embodied in a multiple access, spread-spectrum communication system which processes a

plurality of information signals received simultaneously over telecommunication lines for simultaneous transmission over a radio frequency (RF) channel as a code-division-multiplexed (CDM) signal. The system includes a radio carrier station (RCS) which receives a call request signal that corresponds to a telecommunication line information signal, and a user identification signal that identifies a user to which the call request and information signal are addressed. The receiving apparatus is coupled to a plurality of code division multiple access (CDMA) modems, one of which provides a global pilot code signal and a plurality of message code signals, and each of the CDMA modems combines one of the plurality of information signals with its respective message code signal to provide a spread-spectrum processed signal. The plurality of message code signals of the plurality of CDMA modems are synchronized to the global pilot code signal. The system also includes assignment apparatus that is responsive to a channel assignment signal for coupling the respective information signals received on the telecommunication lines to indicated ones of the plurality of modems; The assignment apparatus is coupled to a time-slot exchange means. The system further includes a system channel controller coupled to a remote call-processor and to the time-slot exchange means. The system channel controller is responsive to the user identification signal, to provide the channel assignment signal. In the system, an RF transmitter is connected to all of the modems to combine the plurality of spread-spectrum processed message signals with the global pilot code signal to generate a CDM signal. The RF transmitter also modulates a carrier signal with the CDM signal and transmits the modulated carrier signal through an RF communication channel.

The transmitted CDM signal is received from the RF communication channel by a subscriber unit (SU) which processes and reconstructs the transmitted information signal assigned to the subscriber. The SU includes a receiving means for receiving and demodulating the CDM signal from the carrier. In addition, the SU comprises a subscriber unit controller and a CDMA modem which includes a processing means for acquiring the global pilot code and despreading the spread-spectrum processed signal to reconstruct the transmitted information signal.

The RCS and the SUs each contain CDMA modems for transmission and reception of telecommunication signals including information signals and connection control signals. The CDMA modem comprises a modem transmitter having: a code generator for providing an associated pilot code signal and for generating a plurality of message code signals; a spreading means for combining each of the information signals, with a respective one of the message code signals to generate spread-spectrum processed message signals; and a global pilot code generator which provides a global pilot code signal to which the message code signals are synchronized.

The CDMA modem also comprises a modem receiver having associated pilot code acquisition and tracking logic. The associated pilot code acquisition logic includes an associated pilot code generator; a group of associated pilot code correlators for correlating code-phase delayed versions of the associated pilot signal with a receive CDM signal for producing a despread associated pilot signal. The code phase of the associated pilot signal is changed responsive to an acquisition signal value until a detector indicates the presence of the despread associated pilot code signal by changing the acquisition signal value. The associated pilot code signal is synchronized to the global pilot signal. The associated pilot code tracking logic adjusts the associated pilot code signal in phase responsive to the acquisition signal so that the signal power level of the despread associated pilot code signal is maximized. Finally, the CDMA modem receiver includes a group of message signal acquisition circuits. Each message signal acquisition circuit includes a plurality of receive message signal correlators for correlating one of the local receive message code signals with the CDM signal to produce a respective despread receive message signal.

To generate large families of nearly mutually orthogonal codes used by the CDMA modems, the present invention includes a code sequence generator. The code sequences are assigned to a respective logical channel of the spread-spectrum communication system, which includes In-phase (I) and Quadrature (Q) transmission over RF communication channels. One set of sequences is used as pilot sequences which are code sequences transmitted without modulation by a data signal. The code sequence generator circuit includes a long code sequence generator including a linear feedback shift register, a memory which provides a short, even code sequence, and a plurality of cyclic shift, feedforward sections which provide other members of the code family which exhibit minimal correlation with the code sequence applied to the feedforward circuit. The code sequence generator further includes a group of code sequence combiners for combining each phase shifted version of the long code sequence with the short, even code sequence to produce a group, or family, of nearly mutually orthogonal codes.

Further, the present invention includes several methods for efficient utilization of the spread-spectrum channels. First, the system includes a bearer channel modification system which comprises a group of message channels between a first transceiver and second transceiver. Each of the group of message channels supports a different information signal transmission rate. The first transceiver monitors a received information signal to determine the type of information signal that is received, and produces a coding signal relating to the coding signal. If a certain type of information signal is present, the first transceiver switches transmission from a first message channel to a second message channel to support the different transmission rate. The coding signal is transmitted by the first transceiver to the second transceiver, and the second transceiver switches to the second message channel to receive the information signal at a different transmission rate.

Another method to increase efficient utilization of the bearer message channels is the method of idle-code suppression used by the present invention. The spread-spectrum transceiver receives a digital data information signal including a predetermined flag pattern corresponding to an idle period. The method includes the steps of: 1) delaying and monitoring the digital data signal; 2) detecting the predetermined flag pattern; 3) suspending transmission of the digital data signal when the flag pattern is detected; and 4) transmitting the data signal as a spread-spectrum signal when the flag pattern is not detected.

The present invention includes a system and method for closed loop automatic power control (APC) for the RCS and SUs of the spread-spectrum communication system. The SUs transmit spread-spectrum signals, the RCS acquires the spread-spectrum signals, and the RCS detects the received power level of the spread-spectrum signals plus any interfering signal including noise. The APC system includes the RCS and a plurality of SUs, wherein the RCS transmits a plurality of forward channel information signals to the SUs

as a plurality of forward channel spread-spectrum signals having a respective forward transmit power level, and each SU transmits to the base station at least one reverse spread-spectrum signal having a respective reverse transmit power level and at least one reverse channel spread-spectrum signal which includes a reverse channel information signal.

The APC includes an automatic forward power control (AFPC) system, and an automatic reverse power control (ARPC) system. The AFPC system operates by measuring, at the SU, a forward signal-to-noise ratio of the respective forward channel information signal, generating a respective forward channel error signal corresponding to a forward error between the respective forward signal-to-noise ratio and a pre-determined signal-to-noise value, and transmitting the respective forward channel error signal as part of a respective reverse channel information signal from the SU to the RCS. The RCS includes a plural number of AFPC receivers for receiving the reverse channel information signals and extracting the forward channel error signals from the respective reverse channel information signals. The RCU also adjusts the respective forward transmit power level of each one of the respective forward spread-spectrum signals responsive to the respective forward error signal.

The ARPC system operates by measuring, in the RCS, a reverse signal-to-noise ratio of each of the respective reverse channel information signals, generating a respective reverse channel error signal representing an error between the respective reverse channel signal-to-noise ratio and a respective pre-determined signal-to-noise value, and transmitting the respective reverse channel error signal as a part of a respective forward channel information signal to the SU. Each SU includes an ARPC receiver for receiving the forward channel information signal and extracting the respective reverse error signal from the forward channel information signal. The SU adjusts the reverse transmit power level of the respective reverse spread-spectrum signal responsive to the respective reverse error signal.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a code division multiple access communication system according to the present invention.

FIG. 2*a* is a block diagram of a 36 stage linear shift register suitable for use with long spreading code of the code generator of the present invention.

FIG. 2*b* is a block diagram of circuitry which illustrates the feed-forward operation of the code generator.

FIG. 2*c* is a block diagram of an exemplary code generator of the present invention including circuitry for generating spreading code sequences from the long spreading codes and the short spreading codes.

FIG. 2*d* is an alternate embodiment of the code generator circuit including delay elements to compensate for electrical circuit delays.

FIG. 3*a* is a graph of the constellation points of the pilot spreading code QPSK signal.

FIG. 3*b* is a graph of the constellation points of the message channel QPSK signal.

FIG. 3*c* is a block diagram of exemplary circuitry which implements the method of tracking the received spreading code phase of the present invention.

FIG. 4 is a block diagram of the tracking circuit that tracks the median of the received multipath signal components.

FIG. 5*a* is a block diagram of the tracking circuit that tracks the centroid of the received multipath signal components.

FIG. 5*b* is a block diagram of the Adaptive Vector Correlator.

FIG. 6 is a block diagram of exemplary circuitry which implements the acquisition decision method of the correct spreading code phase of the received pilot code of the present invention.

FIG. 7 is a block diagram of an exemplary pilot rake filter which includes the tracking circuit and digital phase locked loop for despreading the pilot spreading code, and generator of the weighting factors of the present invention.

FIG. 8*a* is a block diagram of an exemplary adaptive vector correlator and matched filter for despreading and combining the multipath components of the present invention.

FIG. 8*b* is a block diagram of an alternative implementation of the adaptive vector correlator and adaptive matched filter for despreading and combining the multipath components of the present invention.

FIG. 8*c* is a block diagram of an alternative embodiment of the adaptive vector correlator and adaptive matched filter for despreading and combining the multipath components of the present invention.

FIG. 8*d* is a block diagram of the Adaptive Matched Filter of one embodiment of the present invention.

FIG. 9 is a block diagram of the elements of an exemplary radio carrier station (RCS) of the present invention.

FIG. 10 is a block diagram of the elements of an exemplary multiplexer suitable for use in the RCS shown in FIG. 9.

FIG. 11 is a block diagram of the elements of an exemplary wireless access controller (WAC) of the RCS shown in FIG. 9.

FIG. 12 is a block diagram of the elements of an exemplary modem interface unit (MIU) of the RCS shown in FIG. 9.

FIG. 13 is a high level block diagram showing the transmit, receive, control, and code generation circuitry of the CDMA modem.

FIG. 14 is a block diagram of the transmit section of the CDMA modem.

FIG. 15 is a block diagram of an exemplary modem input signal receiver.

FIG. 16 is a block diagram of an exemplary convolutional encoder as used in the present invention.

FIG. 17 is a block diagram of the receive section of the CDMA modem.

FIG. 18 is a block diagram of an exemplary adaptive matched filter as used in the CDMA modem receive section.

FIG. 19 is a block diagram of an exemplary pilot rake as used in the CDMA modem receive section.

FIG. 20 is a block diagram of an exemplary auxiliary pilot rake as used in the CDMA modem receive section.

FIG. 21 is a block diagram of an exemplary video distribution circuit (VDC) of the RCS shown in FIG. 9.

FIG. 22 is a block diagram of an exemplary OF transmitter/receiver and exemplary power amplifiers of the RCS shown in FIG. 9.

FIG. 23 is a block diagram of an exemplary subscriber unit (SU) of the present invention.

FIG. 24 is a flow-chart diagram of an exemplary call establishment algorithm for an incoming call request used by the present invention for establishing a bearer channel between an RCS and an SU.

FIG. 25 is a flow-chart diagram of an exemplary call establishment algorithm for an outgoing call request used by the present invention for establishing a bearer channel between an RCS and an SU.

FIG. 26 is a flow-chart diagram of an exemplary maintenance power control algorithm of the present invention.

FIG. 27 is a flow-chart diagram of an exemplary automatic forward power control algorithm of the present invention.

FIG. 28 is a flow-chart diagram of an exemplary automatic reverse power control algorithm of the present invention.

FIG. 29 is a block diagram of an exemplary closed loop power control system of the present invention when the bearer channel is established.

FIG. 30 is a block diagram of an exemplary closed loop power control system of the present invention during the process of establishing the bearer channel.

GLOSSARY OF ACRONYMS

GLOSSARY OF ACRONYMS

Acronym	Definition
AC	Assigned Channels
A/D	Analog-to-Digital
ADPCM	Adaptive Differential Pulse Code Modulation
AFPC	Automatic Forward Power Control
AGC	Automatic Gain Control
AMF	Adaptive Matched Filter
APC	Automatic Power Control
ARPC	Automatic Reverse Power Control
ASPT	Assigned Pilot
AVC	Adaptive Vector Correlator
AXCH	Access Channel
B-CDMA	Broadband Code Division Multiple Access
BCM	Bearer Channel Modification
BER	Bit Error Rate
BS	Base Station
CC	Call Control
CDM	Code Division Multiplex
CDMA	Code Division Multiple Access
CLK	Clock Signal Generator
CO	Central Office
CTCH	Control Channel
CUCH	Check-Up Channel
dB	Decibels
DCC	Data Combiner Circuitry
DI	Distribution Interface
DLL	Delay Locked Loop
DM	Delta Modulator
DS	Direct Sequence
EPIC	Extended PCM Interface Controller
FBCH	Fast Broadcast Channel
FDM	Frequency Division Multiplex
FD/TDMA	Frequency & Time Division Systems
FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
FSK	Frequency Shift Keying
FSU	Fixed Subscriber Unit
GC	Global Channel
GLPT	Global Pilot
GPC	Global Pilot Code
GPSK	Gaussian Phase Shift Keying
GPS	Global Positioning System
HPPC	High Power Passive Components
HSB	High Speed Bus
I	In-Phase
IC	Interface Controller
ISDN	Integrated Services Digital Network
ISST	Initial System Signal Threshold
LAXPT	Long Access Pilot

-continued

GLOSSARY OF ACRONYMS

Acronym	Definition
LAPD	Link Access Protocol
LCT	Local Craft Terminal
LE	Local Exchange
LFSR	Linear Feedback Shift Register
LI	Line Interface
LMS	Least Mean Square
LOL	Loss of Code Lock
LPF	Low Pass Filter
LSR	Linear Shift Register
MISR	Modem Input Signal Receiver
MIU	Modem Interface Unit
MM	Mobility Management
MOI	Modem Output Interface
MPC	Maintenance Power Control
MSK	M-ary Phase Shift Keying
MSK	Minimum Shift Keying
MSU	Mobile Subscriber Unit
NE	Network Element
OMS	Operation and Maintenance System
OS	Operations System
OQPSK	Offset Quadrature Phase Shift Keying
OW	Order Wire
PARK	Portable Access Rights Key
PBX	Private Branch Exchange
PCM	Pulse Coded Modulation
PCS	Personal Communication Services
PG	Pilot Generator
PLL	Phase Locked Loop
PLT	Pilot
PN	Pseudonoise
POTS	Plain Old Telephone Service
PSTN	Public Switched Telephone Network
Q	Quadrature
QPSK	Quadrature Phase Shift Keying
RAM	Random Access Memory
RCS	Radio Carrier Station
RDI	Receiver Data Input Circuit
RDU	Radio Distribution Unit
RF	Radio Frequency
RLL	Radio Local Loop
SAXPT	Short Access Channel Pilots
SBCH	Slow Broadcast Channel
SHF	Super High Frequency
SIR	Signal Power to Interface Noise Power Ratio
SLIC	Subscriber Line Interface Circuit
SNR	Signal-to-Noise Ratio
SPC	Service PC
SPRT	Sequential Probability Ratio Test
STCH	Status Channel
SU	Subscriber Unit
TDM	Time Division Multiplexing
TMN	Telecommunication Management Network
TRCH	Traffic Channels
TSI	Time-Slot Interchanger
TX	Transmit
TXIDAT	I-Modem Transmit Data Signal
TXQDAT	Q-Modem Transmit Data Signal
UHF	Ultra High Frequency
VCO	Voltage Controlled Oscillator
VDC	Video Distribution Circuit
VGA	Variable Gain Amplifier
VHF	Very High Frequency
WAC	Wireless Access Controller

DESCRIPTION OF THE EXEMPLARY EMBODIMENT

General System Description

The system of the present invention provides local-loop telephone service using radio links between one or more base stations and multiple remote subscriber units. In the exemplary embodiment, a radio link is described for a base

station communicating with a fixed subscriber unit (FSU), but the system is equally applicable to systems including multiple base stations with radio links to both FSUs and Mobile Subscriber Units (MSUs). Consequently, the remote subscriber units are referred to herein as Subscriber Units (SUs).

Referring to FIG. 1, Base Station (BS) **101** provides call connection to a local exchange (LE) **103** or any other telephone network switching interface, such as a private branch exchange (PBX) and includes a Radio Carrier Station (RCS) **104**. One or more RCSs **104**, **105**, **110** connect to a Radio Distribution Unit (RDU) **102** through links **131**, **132**, **137**, **138**, **139**, and RDU **102** interfaces with LE **103** by transmitting and receiving call set-up, control, and information signals through telco links **141**, **142**, **150**. SUs **116**, **119** communicate with the RCS **104** through radio links **161**, **162**, **163**, **164**, **165**. Alternatively, another embodiment of the invention includes several SUs and a "master" SU with functionality similar to the RCS. Such an embodiment may or may not have connection to a local telephone network.

The radio links **161** to **165** operate within the frequency bands of the DCS1800 standard (1.71–1.785 Ghz and 1.805–1.880 GHz); the US-PCS standard (1.85–1.99 Ghz); and the CEPT standard (2.0–2.7 GHz). Although these bands are used in described embodiment, the invention is equally applicable to the entire UHF to SH bands, including bands from 2.7 GHz to 5 GHz. The transmit and receive bandwidths are multiples of 3.5 MS starting at 7 MHz, and multiples of 5 MHz starting at 10 MHz, respectively. The described system includes bandwidths of 7, 10, 10.5, 14 and 15 MHz. In the exemplary embodiment of the invention, the minimum guard band between the Uplink and Downlink is 20 MHz, and is desirably at least three times the signal bandwidth. The duplex separation is between 50 to 175 MHz, with the described invention using 50, 75, 80, 95, and 175 MHz. Other frequencies may also be used.

Although the described embodiment uses different spread-spectrum bandwidths centered around a carrier for the transmit and receive spread-spectrum channels, the present method is readily extended to systems using multiple spread-spectrum bandwidths for the transmit channels and multiple spread-spectrum bandwidths for the receive channels. Alternatively, because spread-spectrum communication systems have the inherent feature that one user's transmission appears as noise to another user's despreading receiver, an embodiment may employ the same spread-spectrum channel for both the transmit and receive path channels. In other words, Uplink and Downlink transmissions can occupy the same frequency band. Furthermore, the present method may be readily extended to multiple CDMA frequency bands, each conveying a respectively different set of messages, uplink, downlink or uplink and downlink.

The spread binary symbol information is transmitted over the radio links **161** to **165** using Quadrature Phase Shift Keying (QPSK) modulation with Nyquist Pulse Shaping in the present embodiment, although other modulation techniques may be used, including, but not limited to, Offset QPSK (OQPSK) and Minimum Shift Keying (MSK). Gaussian Phase Shift Keying (GPSK) and M-ary Phase Shift Keying (MPSK)

The radio links 161 to 165 incorporate Broadband Code Division Multiple Access (B-CDMA™) as the mode of transmission in both the Uplink and Downlink directions. CDMA (also known as Spread Spectrum) communication techniques used in multiple access systems are well-known, and are described in U.S. Pat. No. 5,228,056 entitled SYNCHRONOUS SPREAD-SPECTRUM COMMUNICATION SYSTEM AND METHOD by Donald T Schilling. The system described utilizes the Direct Sequence (DS) spreading technique. The CDMA modulator performs the spread-spectrum spreading code sequence generation, which can be a pseudonoise (PN) sequence; and complex DS modulation of the QPSK signals with spreading code sequences for the In-phase (I) and Quadrature (Q) channels. Pilot signals are generated and transmitted with the modulated signals, and pilot signals of the present embodiment are spreading codes not modulated by data. The pilot signals are used for synchronization, carrier phase recovery, and for estimating the impulse response of the radio channel. Each SU includes a single pilot generator and at least one CDMA modulator and demodulator, together known as a CDMA modem. Each RCS **104**, **105**, **110** has a single pilot generator plus sufficient CDMA modulators and demodulators for all of the logical channels in use by all SUs.

The CDMA demodulator despreads the signal with appropriate processing to combat or exploit multipath propagation effects. Parameters concerning the received power level are used to generate the Automatic Power Control (APC) information which, in turn, is transmitted to the other end of the communication link. The APC information is used to control transmit power of the automatic forward power control (AFPC) and automatic reverse power control (ARPC) links In addition, each RCS **104**, **105** and **110** can perform Maintenance Power Control (PC), in a manner similar to APC, to adjust the initial transmit power of each SU **111**, **112**, **115**, **117** and **118**. Demodulation is coherent where the pilot signal provides the phase reference.

The described radio links support multiple traffic channels with data rates of 8, 16, 32, 64, 128, and 144 kb/s. The physical channel to which a traffic channel is connected operates with a 64 k symbol/sec rate. Other data rates may be supported, and Forward Error Correction (FEC) coding can be employed. For the described embodiment, FEC with coding rate of ½ and constraint length 7 is used. Other rates and constraint lengths can be used consistent with the code generation techniques employed.

Diversity combining at the radio antennas of RCS **104**, **105** and **110** is not necessary because CDMA has inherent frequency diversity due to the spread bandwidth. Receivers include Adaptive Matched Filters (AMFs) (not shown in FIG. 1) which combine the multipath signals. In the present embodiment, the exemplary AMFs perform Maximal Ratio Combining.

Referring to FIG. 1, RCS **104** interfaces to RDU **102** through links **131**, **132**, **137** with, for example, 1.544 Mb/s DS1, 2.048 Mb/s E1; or HDSL Formats to receive and send digital data signals. While these are typical telephone company standardized interfaces, the present invention is not limited to these digital data formats only. The exemplary RCS line interface (not shown in FIG. 1) translates the line coding (such as HDB3, B8ZS, AMI) and extracts or produces framing information, performs Alarms and Facility signaling functions, as well as channel specific loop-back and parity check functions. The interfaces for this description provide 64 kb/s PCM encoded or 32 kb/s ADPCM encoded telephone traffic channels or ISDN channels to the RCS for processing. Other ADPCM encoding techniques can be used consistent with the sequence generation techniques.

The system of the present invention also supports bearer rate modification between the RCS **104** and each SU **111**, **112**, **115**, **117** and **118** communicating with RCS **104** in

which a CDMA message channel supporting 64 kb/s may be assigned to voiceband data or FAX when rates above 4.8 kb/s are present. Such 64 kb/s bearer channel is considered an unencoded channel. For ISDN, bearer rate modification may be done dynamically, based upon the D channel messages.

In FIG. 1, each SU **111**, **112**, **115**, **117** and **118** either includes or interfaces with a telephone unit **170**, or interfaces with a local switch (PBX) **171**. The input from the telephone unit may include voice, voiceband data and signaling. The SU translates the analog signals into digital sequences, and may also include a Data terminal **172** or an ISDN interface **173**. The SU can differentiate voice input, voiceband data or FAX and digital data. The SU encodes voice data with techniques such as ADPCM at 32 kb/s or lower rates, and detects voiceband data or FAX with rates above 4.8 kb/s to modify the traffic channel (bearer rate modification) for unencoded transmission. Also, A-law, u-law, or no companding of the signal may be performed before transmission. For digital data, data compression techniques, such as idle flag removal, may also be used to conserve capacity and minimize interference.

The transmit power levels of the radio interface between RCS **104** and SUs **111**, **112**, **115**, **117** and **118** are controlled using two different closed loop power control methods. The Automatic Forward Power Control (AFPC) method determines the Downlink transmit power level, and the Automatic Reverse Power Control (ARPC) method determines the Uplink transmit power level. The logical control channel by which SU **111** and RCS **104**, for example, transfer power control information operates at least a 16 kHz update rate. Other embodiments may use a faster or slower update rate for example 64 kHz. These algorithms ensure that the transmit power of a user maintains an acceptable Bit-Error Rate (BER), maintains the system power at a minimum to conserve power, and maintains the power level of all SUs **111**, **112**, **115**, **117** and **118** received by RCS **104** at a nearly equal level.

In addition, the system uses an optional maintenance power control method during the inactive mode of a SU. When SU **111** is inactive or powered-down to conserve power, the unit occasionally activates to adjust its initial transmit power level setting in response to a maintenance power control signal from RCS **104**. The maintenance power signal is determined by the RCS **104** by measuring the received power level of SU **111** and present system power level and, from this, calculates the necessary initial transmit power. The method shortens the channel acquisition time of SU **111** to begin a communication. The method also prevents the transmit power level of SU **111** from becoming too high and interfering with other channels during the initial transmission before the closed loop power control reduces the transmit power.

RCS **104** obtains synchronization of its clock from an interface line such as, but not limited to, E1, T1, or HDSL interfaces. RCS **104** can also generate its own internal clock signal from an oscillator which may be regulated by a Global Positioning System (GPS) receiver. RCS **104** generates a Global Pilot Code, a channel with a spreading code but no data modulation, which can be acquired by remote SUs **111** through **118**. All transmission channels of the RCS are synchronized to the Pilot channel, and spreading code phases of code generators (not shown) used for Logical communication channels within RCS **104** are also synchronized to the Pilot channel's spreading code phase. Similarly, SUs **111** through **118** which receive the Global Pilot Code of RCS **104** synchronize the spreading and de-spreading code phases of the code generators (not shown) of the SUs to the Global Pilot Code.

RCS **104**, SU **111**, and RDU **102** may incorporate system redundancy of system elements and automatic switching between internal functional system elements upon a failure event to prevent loss or drop-out of a radio link, power supply, traffic channel, or group of traffic channels.

Logical Communication Channels

A 'channel' of the prior art is usually regarded as a communications path which is part of an interface and which can be distinguished from other paths of that interface without regard to its content. However, in the case of CDMA, separate communications paths are distinguished only by their content. The term 'logical channel' is used to distinguish the separate data streams, which are logically equivalent to channels in the conventional sense. All logical channels and sub-channels of the present invention are mapped to a common 64 kilo-symbols per second (ksym/s) QPSK stream. Some channels are synchronized to associated pilot codes which are generated from, and perform a similar function to the system Global Pilot Code (GPC). The system pilot signals are not, however, considered logical channels.

Several logical communication channels are used over the RF communication link between the RCS and SU. Each logical communication channel either has a fixed, predetermined spreading code or a dynamically assigned spreading code. For both pre-determined and assigned codes, the code phase is synchronized with the Pilot Code. Logical communication channels are divided into two groups: the Global Channel (GC) group includes channels which are either transmitted from the base station RCS to all remote SUs or from any SU to the RCS of the base station regardless of the SU's identity. The channels in the GC group may contain information of a given type for all users including those channels used by SUs to gain system access. Channels in the Assigned Channels (AC) group are those channels dedicated to communication between the RCS and a particular SU.

The Global Channels (GC) group provides for 1) Broadcast Control logical channels, which provide point to multipoint services for broadcasting messages to all SUs and paging messages to SUs; and 2) Access Control logical channels which provide point-to-point services on global channels for SUs to access the system and obtain assigned channels.

The RCS of the present invention has multiple Access Control logical channels, and one Broadcast Control group. An SU of the present invention has at least one Access Control channel and at least one Broadcast Control logical channel.

The Global logical channels controlled by the RCS are the Fast Broadcast Channel (FBCH) which broadcasts fast changing information concerning which services and which access channels are currently available, and the Slow Broadcast Channel (SBCH) which broadcasts slow changing system information and paging messages. The Access Channel (AXCH) is used by the SUs to access an RCS and gain access to assigned channels. Each AXCH is paired with a Control Channel (CTCH). The CTCH is used by the RCS to acknowledge and reply to access attempts by SUs. The Long Access Pilot (LAW is transmitted synchronously with AXCH to provide the RCS with a time and phase reference.

An Assigned Channel (AC) group contains the logical channels that control a single telecommunication connection

between the RCS and an SU. The functions developed when an AC group is formed include a pair of power control logical message channels for each of the Uplink and Downlink connections, and depending on the type of connection, one or more pairs of traffic channels. The Bearer Control function performs the required forward error control, bearer rate modification, and encryption functions.

Each SU 111, 112, 115, 117 and 118 has at least one AC group formed when a telecommunication connection exists, and each RCS 104, 105 and 110 has multiple AC groups formed, one for each connection in progress. An AC group of logical channels is created for a connection upon successful establishment of the connection. The AC group includes encryption, FEC coding, and multiplexing on transmission, and FEC decoding, deception and demultiplexing on reception.

Each AC group provides a set of connection oriented point-to-point services and operates in both directions between a specific RCS, for example, RCS 104 and a specific SU, for example, SU 111. An AC group formed for a connection can control more than one bearer over the RF communication channel associated with a single connection. Multiple bearers are used to carry distributed data such as, but not limited to, ISDN. An AC group can provide for the duplication of traffic channels to facilitate switch over to 64 kb/s PCM for high speed facsimile and modem services for the bearer rate modification function.

The assigned logical channels formed upon a successful call connection and included in the AC group are a dedicated signaling channel [order wire (OW)], an APC channel, and one or more Traffic channels (TRCH) which are bearers of 8, 16, 32, pr 64 kb/s depending on the service supported. For voice traffic, moderate rate coded speech, ADPCM, or PCM can be supported on the Traffic channels. For ISDN service types, two 64 kb/s TRCHs form the B channels and a 16 kb/s ARCH forms the D channel. Alternatively, the APC subchannel may either be separately modulated on its own CDMA channel, or may be time division multiplexed with a traffic channel or OW channel.

Each SU 111, 112, 115, 117 and 118 of the present invention supports up to three simultaneous traffic channels. The mapping of the three logical channels for TRCHs to the user data is shown below in Table 1:

TABLE 1

Mapping of service types to the three available TRCH channels

Service	TRCH(0)	TRCH(1)	TRCH(2)
16 kb/s POTS	TRCH/16	not used	not used
32 + 64 kb/s POTS (during BCM)	TRCH/32	TRCH/64	not used
32 kb/s POTS	TRCH/32	not used	not used
64 kb/s POTS	not used	TRCH/64	not used
ISDN D	not used	not used	TRCH/16
ISDN B + D	TRCH/64	not used	TRCH/16
ISDN 2B + D	TRCH/64	TRCH/64	TRCH/16
Digital LL @ 64 kb/s	TRCH/64	not used	not used
Digital LL @ 2 × 64 kb/s	TRCH/64	TRCH/64	not used
Analog LL @ 64 kb/s	TRCH/64	not used	not used

The APC data rate is sent at 64 kb/s. The APC logical channel is not FEC coded to avoid delay and is transmitted at a relatively low power level to minimize capacity used for APC. Alternatively, the APC and OW may be separately modulated using complex spreading code sequences, or they may be time division multiplexed.

The OW logical channel is FEC coded with a rate ½ convolutional code. This logical channel is transmitted in bursts when signaling data is present to reduce interference. After an idle period, the OW signal begins with at least 35 symbols prior to the start of the data frame. For silent maintenance call data, the OW is transmitted continuously between frames of data. Table 2 summarizes the logical channels used in the exemplary embodiment:

TABLE 2

Logical Channels and sub-channels of the B-CDMA Air Interface

Channel name	Abbr.	Brief Description	Direction (forward or reverse)	Bit rate	Max BER	Power level	Pilot
Global Channels							
Fast Broadcast Channel	FBCH	Broadcasts fast-changing system information	F	16 kb/s	1e-4	Fixed	GLPT
Slow Broadcast Channel	SBCH	Broadcasts paging messages to FSUs and slow-changing system information	F	16 kb/s	1e-7	Fixed	GLPT
Access Channels	AXCH(i)	For initial access attempts by FSUs	R	32 kb/s	1e-7	Controlled by APC	LAXPT(i)
Control Channels	CTCH(i)	For granting access	F	32 kb/s	1e-7	Fixed	GLPT
Assigned Channels							
16 kb/s POTS	TRCH /16	General POTS use	F/R	16 kb/s	1e-4	Controlled by APC	F-GLPT R-ASPT
32 kb/s POTS	TRCH /32	General POTS use	F/R	32 kb/s	1e-4	Controlled by APC	F-GLPT R-ASPT
64 kb/s	TRCH	POTS use for	F/R	64	1e-4	Controlled	F-GLPT

TABLE 2-continued

Logical Channels and sub-channels of the B-CDMA Air Interface

Channel name	Abbr.	Brief Description	Direction (forward or reverse)	Bit rate	Max BER	Power level	Pilot
POTS	/64	in-band modems/fax		kb/s		by APC	R-ASPT
D channel	TRCH /16	ISDN D channel	F/R	16 kb/s	1e-7	Controlled by APC	F-GLPT R-ASPT
Order wire channel	OW	assigned signaling channel	F/R	32 kb/s	1e-7	Controlled by APC	F-GLPT R-ASPT
APC channel	APC	carries APC commands	F/R	64 kb/s	2e-1	Controlled by APC	F-GLPT R-ASPT

The Spreading Codes

The CDMA code generators used to encode the logical channels of the present invention employ Linear Shift Registers (LSRs) with feedback logic which is a method well known in the art. The code generators of the present embodiment of the invention generate 64 synchronous unique sequences. Each RF communication channel uses a pair of these sequences for complex spreading (in-phase and quadrature) of the logical channels, so the generator gives 32 complex spreading sequences. The sequences are generated by a single seed which is initially loaded into shift register circuit.

The Generation of Spreading Code Sequences and Seed Selection

The spreading code period of the present invention is defined as an integer multiple of the symbol duration, and the beginning of the code period is also the beginning of the symbol. The relation between bandwidths and the symbol lengths chosen for the exemplary embodiment of the present invention is:

BW (MHZ)	L (chips/symbol)
7	91
10	130
10.5	133
14	182
15	195

The spreading code length is also a multiple of 64 and of 96 for ISDN frame support. The spreading code is a sequence of symbols, called chips or chip values. The general methods of generating pseudorandom sequences using Galois Field mathematics is known to those skilled in the art; however, a unique set, or family, of code sequenced has been derived for the present invention. First, the length of the linear feedback shift register to generate a code sequence is chosen, and the initial value of the register is called a "seed". Second, the constraint is imposed that no code sequence generated by a code seed may be a cyclic shift of another code sequence generated by the same code seed. Finally, no code sequence generated from one seed may be a cyclic shift of a code sequence generated by another seed.

It has been determined that the spreading code length of chip values of the present invention is:

$$128 \times 233415 = 29877120 \tag{1}$$

The spreading codes are generated by combining a linear sequence of period 233415 and a nonlinear sequence of period 128

The FBCH channel of the exemplary embodiment is an exception because it is not coded with the 128 length sequence, so the FBCH channel spreading code has period 233415.

The nonlinear sequence of length 128 is implemented as a fixed sequence loaded into a shift register with a feed-back connection. The fixed sequence can be generated by an m-sequence of length 127 padded with an extra logic 0, 1, or random value as is well known in the art.

The linear sequence of length L=233415 is generated using a linear feedback shift register (LFSR) circuit with 36 stages. The feedback connections correspond to a irreducible polynomial h(n) of degree 36. The polynomial h(x) chosen for the exemplary embodiment of the present invention is

$$h(x)=x^{36}+x^{35}+x^{30}+x^{28}+x^{26}+x^{25}+x^{22}+x^{20}+x^{19}+x^{17}+x^{16}+x^{15}+x^{14}+x^{12}+x^{11}+x^{9}+x^{8}+x^{4}+x^{3}+x^{2}+x^{1}$$

or, in binary notation

$$h(x)=(1100001010110010110111101101100011101) \tag{2}$$

A group of "seed" values for a LFSR representing the polynomial h(x) of equation (2) which generates code sequences that are nearly orthogonal with each other is determined. The first requirement of the seed values is that the seed values do not generate two code sequences which are simply cyclic shifts of each other.

The seeds are represented as elements of $GF(2^{36})$ which is the field of residue classes modulo h(x). This field has a primitive element $\delta=x^2+x+1$. The binary representation of δ is

$$\delta=000000000000000000000000000000000111 \tag{3}$$

Every element of $GF(2^{36})$ can also be written as a power of δ reduced modulo h(x). Consequently, the seeds are represented as powers of δ, the primitive element.

The solution for the order of an element does not require a search of all values; the order of an element divides the order of the field ($GF(2^{36})$). When 6 is any element of $GF(2^{36})$ with

$$x^e \equiv 1 \tag{4}$$

for some e, then $e|2^{36}-1$. Therefore, the order of any element in $GF(2^{36})$ divides $2^{36}-1$.

Using these constraints, it has been determined that a numerical search generates a group of seed values, n, which are powers of δ, the primitive element of h(x).

The present invention includes a method to increase the number of available seeds for use in a CDMA communication system by recognizing that certain cyclic shifts of the previously determined code sequences may be used simultaneously. The round trip delay for the cell sizes and bandwidths of the present invention are less than 3000 chips. In one embodiment of the present invention, sufficiently separated cyclic shifts of a sequence can be used within the same cell without causing ambiguity for a receiver attempting to determine the code sequence. This method enlarges the set of sequences available for use.

By implementing the tests previously described, a total of 3879 primary seeds were determined through numerical computation. These seeds are given mathematically as

$$\delta^n \text{modulo } h(x) \tag{5}$$

where 3879 values of n are listed in the Appendix A, with δ=(00, . . . 00111) as before in (3).

When all primary seeds are known, all secondary seeds of the present invention are derived from the primary seeds by shifting them multiples of 4095 chips modulo h(x). Once a family of seed values is determined, these values are stored in memory and assigned to logical channels as necessary. Once assigned, the initial seed value is simply loaded into LFSR to produce the required spreading code sequence associated with the seed value.

Rapid Acquisition Feature of Long and Short codes

Rapid acquisition of the correct code phase by a spread-spectrum receiver is improved by designing spreading codes which are faster to detect. The present embodiment of the invention includes a new method of generating code sequences that have rapid acquisition properties by using one or more of the following methods. First, a long code may be constructed from two or more short codes. The new implementation uses many code sequences, one or more of which are rapid acquisition sequences of length L that have average acquisition phase searches r=log2L. Sequences with such properties are well known to those practiced in the art. The average number of acquisition test phases of the resulting long sequence is a multiple of r=log2L rather than half of the number of phases of the long sequence.

Second, a method of transmitting complex valued spreading code sequences (In-phase (I) and Quadrature (Q) sequences) in a pilot spreading code signal may be used rather than transmitting real valued sequences. Two or more separate code sequences may be transmitted over the complex channels. If the sequences have different phases, an acquisition may be done by acquisition circuits in parallel over the different code sequences when the relative phase shift between the two or more code channels is known. For example, for two sequences, one can be sent on an In phase (I) channel and one on the Quadrature (Q) channel. To search the code sequences, the acquisition detection means searches the two channels, but begins the (Q) channel with an offset equal to one-half of the spreading code sequence length. With code sequence length of N, the acquisition means starts the search at N/2 on the (Q) channel. The average number of tests to find acquisition is N/2 for a single code search, but searching the (I) and phase delayed (Q) channel in parallel reduces the average number of tests to N/4. The codes sent on each channel could be the same code, the same code with one channel's code phase delayed, or different code sequences.

Epoch and Sub-epoch Structures

The long complex spreading codes used for the exemplary system of the present invention have a number of chips after which the code repeats. The repetition period of the spreading sequence is called an epoch. To map the logical channels to CDMA spreading codes, the present invention uses an Epoch and Sub-epoch structure. The code period for the CDMA spreading code to modulate logical channels is 29877120 chips/code period which is the same number of chips for all bandwidths. The code period is the epoch of the present invention, and Table 3 below defines the epoch duration for the supported chip rates. In addition, two sub-epochs are defined over the spreading code epoch and are 233415 chips and 128 chips long.

The 233415 chip sub-epoch is referred to as a long sub-epoch, and is used for synchronizing events on the RF communication interface such as encryption key switching and changing from global to assigned codes. The 128 chip short epoch is defined for use as an additional timing reference. The highest symbol rate used with a single CDMA code is 64 ksym/s. There is always an integer number of chips in a symbol duration for the supported symbol rates 64, 32, 16, and 8 ksym/s.

TABLE 3

Bandwidths, Chip Rates, and Epochs

Bandwidth (MHz)	Chip Rate, Complex (Mchip/sec)	number of chips in a 64 kbit/sec symbol	128 chip sub-epoch duration* (μs)	233415 chip sub-epoch duration* (ms)	Epoch duration (sec)
7	5.824	91	21.978	40.078	5.130
10	8.320	130	15.385	28.055	3.591
10.5	8.512	133	15.038	27.422	3.510
14	11.648	182	10.989	20.039	2.565
15	12.480	195	10.256	18.703	2.394

*numbers in these columns are rounded to 5 digits.

Mapping of the Logical Channels to Epochs and Sub-epochs

The complex spreading codes are designed such that the beginning of the sequence epoch coincides with the beginning of a symbol for all of the bandwidths supported. The present invention supports bandwidths of 7, 10, 10.5, 14, and 5 MHz. Assuming nominal 20% roll-off, these bandwidths correspond to the following chip rates in Table 4.

TABLE 4

Supported Bandwidths and Chip Rates for CDMA.

BW (MHz)	R_c (Complex MChips/sec)	Excess BW, %	L:(R_c/L) = 64k	Factorization of L
7	5.824	20.19	91	7 × 13
10	8.320	20.19	130	2 × 5 × 13
10.5	8.512	23.36	133	7 × 19
14	11.648	20.19	182	2 × 7 × 13
15	12.480	20.19	195	3 × 5 × 13

The number of chips in an epoch is:

$$N=29877120=2^7\times3^3\times5\times7\times13\times19 \tag{6}$$

If interleaving is used, the beginning of an interleaver period coincides with the beginning of the sequence epoch. The spreading sequences generated using the method of the present invention can support interleaver periods that are multiples of 1.5 ms for various bandwidths.

Cyclic sequences of the prior art are generated using linear feedback shift register (LFSR) circuits. However, this method does not generate sequences of even length. One embodiment of the spreading code sequence generator using the code seeds generated previously is shown in FIG. 2*a*, FIG. 2*b*, and FIG. 2*c*. The present invention uses a 36 stage LFSR **201** to generate a sequence of period $N'=233415=3^3\times5\times7\times13\times19$, which is C_o in FIG. 2*a*. In FIGS. 2*a*, 2*b*, and 2*c*, the symbol ⊕ represents a binary addition (EXCLUSIVE-OR). A sequence generator designed as above generates the in-phase and quadrature parts of a set of complex sequences. The tap connections and initial state of the 36 stage LFSR determine the sequence generated by this circuit. The tap coefficients of the 36 stage LFSR are determined such that the resulting sequences have the period 233415. Note that the tap connections shown in FIG. 2*a* correspond to the polynomial given in equation (2). Each resulting sequence is then overlaid by binary addition with the 128 length sequence C_* to obtain the epoch period 29877120.

FIG. 2*b* shows a Feed Forward (FF) circuit **202** which is used in the code generator. The signal $X[n-1]$ is output of the chip delay **211**, and the input of the chip delay **211** is $X[n]$. The code chip $C[n]$ is formed by the logical adder **212** from the input $X[n]$ and $X[n-1]$. FIG. 2*c* shows the complete spreading code generator. From the LFSR **201**, output signals go through a chain of up to 63 single stage FFs **203** cascaded as shown. The output of each FF is overlaid with the short, even code sequence C_* period $128=2^7$ which is stored in code memory **222** and which exhibits spectral characteristics of a pseudorandom sequence to obtain the epoch N=29877120. This sequence of 128 is determined by using an m-sequence (PN sequence) of length $127=2^7-1$ and adding a bit-value, such as logic 0, to the sequence to increase the length to 128 chips. The even code sequence C_* is input to the even code shift register **221**, which is a cyclic register, that continually outputs the sequence. The short sequence is then combined with the long sequence using an EXCLUSIVE-OR operation **213**, **214**, **220**.

As shown in FIG. 2*c*, up to 63 spreading code sequences C_o through C_{63} are generated by tapping the output signals of FFs **203** and logically adding the short sequence C_* in binary adders **213**, **214**, and **220**, for example. One skilled in the art would realize that the implementation of FF **203** will create a cumulative delay effect for the code sequences produced at each FF stage in the chain. This delay is due to the nonzero electrical delay in the electronic components of the implementation. The timing problems associated with the delay can be mitigated by inserting additional delay elements into the FF chain in one version of the embodiment of the invention. The FF chain of FIG. 2*c* with additional delay elements is shown in FIG. 2*d*.

The code-generators in the exemplary embodiment of the present invention are configured to generate either global codes, or assigned codes. Global codes are CDMA codes that can be received or transmitted by all users of the system. Assigned codes are CDMA codes that are allocated for a particular connection. When a set of sequences are generated from the same generator as described, only the seed of the 36 stage LFSR is specified to generate a family of sequences. Sequences for all the global codes, are generated using the same LFSR circuit. Therefore, once an SU has synchronized to the Global pilot signal from an RCS and knows the seed for the LFSR circuit for the Global Channel codes, it can generate not only the pilot sequence but also all other global codes used by the RCS.

The signal that is upconverted to RF is generated as follows. The output signals of the above shift register circuits are converted to an antipodal sequence (0 maps into +1, 1 maps into −1). The Logical channels are initially converted to QPSK signals, which are mapped as constellation points as is well known in the art. The In-phase and Quadrature channels of each QPSK signal form the real and imaginary parts of the complex data value. Similarly, two spreading codes are used to form complex spreading chip values. The complex data are spread by being multiplied by the complex spreading code. Similarly, the received complex data is correlated with the conjugate of the complex spreading code to recover despread data.

Short Codes

Short codes are used for the initial ramp-up process when an SU accesses an RCS. The period of the short codes is equal to the symbol duration and the start of each period is aligned with a symbol boundary. Both SU and RCS derive the real and imaginary parts of the short codes from the last eight feed-forward sections of the sequence generator producing the global codes for that cell.

The short codes that are in use in the exemplary embodiment of the invention are updated every 3 ms. Other update times that are consistent with the symbol rate may be used. Therefore, a change-over occurs every 3 ms starting from the epoch boundary. At a change-over, the next symbol length portion of the corresponding feed-forward output becomes the short code. When the SU needs to use a particular short code, it waits until the first 3 ms boundary of the next epoch and stores the next symbol length portion output from the corresponding FF section. This shall be used as the short code until the next change-over, which occurs 3 ms later.

The signals represented by these short codes are known as Short Access Channel pilots (SAXPTs).

Mapping of Logical Channels to Spreading Codes

The exact relationship between the spreading code sequences and the CDMA logical channels and pilot signals is documented in Table 5*a* and Table 5*b*. Those signal names ending in '-CH' correspond to logical channels. Those signal names ending in '-PT' correspond to pilot signals, which are described in detail below.

TABLE 5a

Spreading code sequences and global CDMA codes

Sequence	Quadrature	Logical Channel or Pilot Signal	Direction
C_0	I	FBCH	Forward (F)
C_1	Q	FBCH	F
$C_2 \oplus C^*$	I	GLPT	F
$C_3 C^*$	Q	GLPT	F
$C_4 \oplus C^*$	I	SBCH	F
$C_5 \oplus C^*$	Q	SBCH	F
$C_6 \oplus C^*$	I	CTCH (0)	F
$C_7 \oplus C^*$	Q	CTCH (0)	F
$C_8 \oplus C^*$	I	APCH (1)	F
$C_9 \oplus C^*$	Q	APCH (1)	F
$C_{10} \oplus C_*$	I	CTCH (1)	F
$C_{11} \oplus C_*$	Q	CTCH (1)	F
$C_{12} \oplus C_*$	I	APCH (1)	F
$C_{13} \oplus C_*$	Q	APCH (1)	F
$C_{14} \oplus C_*$	I	CTCH (2)	F
$C_{15} \oplus C_*$	Q	CTCH (2)	F
$C_{16} \oplus C_*$	I	APCH (2)	F
$C_{17} \oplus C_*$	Q	APCH (2)	F
$C_{18} \oplus C_*$	I	CTCH (3)	F

TABLE 5a-continued

Spreading code sequences and global CDMA codes

Sequence	Quadrature	Logical Channel or Pilot Signal	Direction
$C_{19}\oplus C_*$	Q	CTCH (3)	F
$C_{20}\oplus C_*$	I	APCH (3)	F
$C_{21}\oplus C_*$	Q	APCH (3)	F
$C_{22}\oplus C_*$	I	reserved	—
$C_{23}\oplus C_*$	Q	reserved	—
....	....	....	....
....	....	....	....
$C_{40}\oplus C_*$	I	reserved	—
$C_{41}\oplus C_*$	Q	reserved	—
$C_{42}\oplus C_*$	I	AXCH (3)	Reverse (R)
$C_{43}\oplus C_*$	Q	AXCH (3)	R
$C_{44}\oplus C_*$	I	LAXPT (3) SAXPT (3) seed	R
$C_{45}\oplus C_*$	Q	LAXPT (3) SAXPT (3) seed	R
$C_{46}\oplus C_*$	I	AXCH (2)	R
$C_{47}\oplus C_*$	Q	AXCH (2)	R
$C_{48}\oplus C_*$	I	LAXPT (2) SAXPT (2) seed	R
$C_{49}\oplus C_*$	Q	LAXPT (2) SAXPT (2) seed	R
$C_{50}\oplus C_*$	I	AXCH (1)	R
$C_{51}\oplus C_*$	Q	AXCH (1)	R
$C_{52}\oplus C_*$	I	LAXPT (1) SAXPT (1) seed	R
$C_{53}\oplus C_*$	Q	LAXPT (1) SAXPT (1) seed	R
$C_{54}\oplus C_*$	I	AXCH (0)	R
$C_{55}\oplus C_*$	Q	AXCH (0)	R
$C_{56}\oplus C_*$	I	LAXPT (0) SAXPT (0) seed	R
$C_{57}\oplus C_*$	Q	LAXPT (0) SAXPT (0) seed	R
$C_{58}\oplus C_*$	I	IDLE	—
$C_{59}\oplus C_*$	Q	IDLE	—
$C_{60}\oplus C_*$	I	AUX	R
$C_{61}\oplus C_*$	Q	AUX	R
$C_{62}\oplus C_*$	I	reserved	—
$C_{63}\oplus C_*$	Q	reserved	—

TABLE 5b

Spreading code sequences and assigned CDMA codes.

Sequence	Quadrature	Logical Channel or Pilot Signal	Direction
$C_0\oplus C_*$	I	ASPT	Reverse (R)
$C_1\oplus C_*$	Q	ASPT	R
$C_2\oplus C_*$	I	APCH	R
$C_3\oplus C_*$	Q	APCH	R
$C_4\oplus C_*$	I	OWCH	R
$C_5\oplus C_*$	Q	OWCH	R
$C_6\oplus C_*$	I	TRCH (0)	R
$C_7\oplus C_*$	Q	TRCH (0)	R
$C_8\oplus C_*$	I	TRCH (1)	R
$C_9\oplus C_*$	Q	TRCH (1)	R
$C_{10}\oplus C_*$	I	TRCH (2)	R
$C_{11}\oplus C_*$	Q	TRCH (2)	R
$C_{12}\oplus C_*$	I	TRCH (3)	R
$C_{13}\oplus C_*$	Q	TRCH (3)	R
$C_{14}\oplus C_*$	I	reserved	—
$C_{15}\oplus C_*$	Q	reserved	—
....	....	....	....
....	....	....	....
$C_{44}\oplus C_*$	I	reserved	—
$C_{45}\oplus C_*$	Q	reserved	—
$C_{46}\oplus C_*$	I	TRCH (3)	Forward (F)
$C_{47}\oplus C_*$	Q	TRCH (3)	F
$C_{48}\oplus C_*$	I	TRCH (2)	F
$C_{49}\oplus C_*$	Q	TRCH (2)	F

TABLE 5b-continued

Spreading code sequences and assigned CDMA codes.

Sequence	Quadrature	Logical Channel or Pilot Signal	Direction
$C_{50}\oplus C_*$	I	TRCH (1)	F
$C_{51}\oplus C_*$	Q	TRCH (1)	F
$C_{52}\oplus C_*$	I	TRCH (0)	F
$C_{53}\oplus C_*$	Q	TRCH (0)	F
$C_{54}\oplus C_*$	I	OWCH	F
$C_{55}\oplus C_*$	Q	OWCH	F
$C_{56}\oplus C_*$	I	APCH	F
$C_{57}\oplus C_*$	Q	APCH	F
$C_{58}\oplus C_*$	I	IDLE	—
$C_{59}\oplus C_*$	Q	IDLE	—
$C_{60}\oplus C_*$	I	reserved	—
$C_{61}\oplus C_*$	Q	reserved	—
$C_{62}\oplus C_*$	I	reserved	—
$C_{63}\oplus C_*$	Q	reserved	—

For global codes, the seed values for the 36 bit shift register are chosen to avoid using the same code, or any cyclic shift of the same code, within the same geographical area to prevent ambiguity or harmful interference. No assigned code is equal to, or a cyclic shift of a global code.

Pilot Signals

The pilot signals are used for synchronization, carrier phase recovery, and for estimating the impulse response of the radio channel.

The RCS **104** transmits a forward link pilot carrier reference as a complex pilot code sequence to provide time and phase reference for all SUs **111**, **112**, **115**, **117** and **118** in its service area. The power level of the Global Pilot (GLPT) signal is set to provide adequate coverage over the whole RCS service area, which area depends on the cell size With only one pilot signal in the forward link, the reduction in system capacity due to the pilot energy is negligible.

The SUs **111**, **112**, **115**, **117** and **118** each transmits a pilot carrier reference as a quadrature modulated (complex-valued) pilot spreading code sequence to provide a time and phase reference to the RCS for the reverse link. The pilot signal transmitted by the SU of one embodiment of the invention is 6 dB lower than the power of the 32 kb/s POTS traffic channel. The reverse pilot channel is subject to APC. The reverse link pilot associated with a particular connection is called the Assigned Pilot (ASPT). In addition, there are pilot signals associated with access channels. These are called the Long Access Channel Pilots (LAXPTs). Short access channel pilots (SAXPTs) are also associated with the access channels and used for spreading code acquisition and initial power ramp-up

All pilot signals are formed from complex codes, as defined below:

$$GLPT(\text{forward}) = \{C_2 \oplus C_*) + j\cdot(C_3 \oplus C_*)\}\cdot\{(1) + j\cdot(0)\}$$

$$\{\text{Complex Code}\}\cdot\{\text{Carrier}\}$$

The complex pilot signals are de-spread by multiplication with conjugate spreading codes: $\{(C_2 \oplus C_*) - j.(C_3 \oplus C_*)\}$. By contrast, traffic channels are of the form:

$$TRCH_n\text{ (forward/reverse)} = \{(C_k \oplus C_*) + j\cdot(C_1 \oplus C_*)\}\cdot$$

$$\{(\pm 1) + j(\pm 1)\}$$

$$\{\text{Complex Codes}\}\cdot\{\text{Data Symbol}\}$$

which thus form a constellation set at

$$\frac{\pi}{4}$$

radians with respect to the pilot signal constellations.

The GLPT constellation is shown in FIG. 3*a*, and the $TRCH_n$ traffic channel constellation is shown in FIG. 3*b*.

Logical Channel Assignment of the FBCH, SBCH, and Traffic Channels

The FBCH is a global forward link channel used to broadcast dynamic information about the availability of services and AXCHs. Messages are sent continuously over this channel, and each message lasts approximately 1 ms. The FBCH message is 16 bits long, repeated continuously, and is epoch aligned. The FBCH is formatted as defined in Table 6.

TABLE 6

FBCH format

Bit	Definition
0	Traffic Light 0
1	Traffic Light 1
2	Traffic Light 2
3	Traffic Light 3
4–7	service indicator bits
8	Traffic Light 0
9	Traffic Light 1
10	Traffic Light 2
11	Traffic Light 3
12–15	service indicator bits

For the FBCH, bit 0 is transmitted first. As used in Table 6, a traffic light corresponds to an Access Channel (AXCH) and indicates whether the particular access channel is currently in use (a red) or not in use (a green). A logic '1' indicates that the traffic light is green, and a logic '0' indicates the traffic light is red. The values of the traffic light bits may change from octet to octet, and each 16 bit message contains distinct service indicator bits which describe the types of services that are available for the AXCHs.

One embodiment of the present invention uses service indicator bits as follows to indicate the availability of services or AXCHs. The service indicator bits {4,5,6,7,12, 13,14,15} taken together may be an unsigned binary number, with bit 4 as the MSB and bit 15 as the LSB. Each service type increment has an associated nominal measure of the capacity required, and the FBCH continuously broadcasts the available capacity. This is scaled to have a maximum value equivalent to the largest single service increment possible. When an SU requires a new service or an increase in the number of bearers, it compares the capacity required to that indicated by the FBCH, and then considers itself blocked if the capacity is not available. The FBCH and the traffic channels are aligned to the epoch.

Slow Broadcast Information frames contain system or other general information that is available to all SUs and Paging Information frames contain information about call requests for particular SUs. Slow Broadcast Information frames and Paging Information frames are multiplexed together on a single logical channel which forms the Slow Broadcast Channel (SBCH). As previously defined, the code epoch is a sequence of 29 877 20 chips having an epoch duration which is a function of the chip rate defined in Table 7 below. In order to facilitate power saving, the channel is divided into N "Sleep" Cycles, and each Cycle is subdivided into M Slots, which are 19 ms long, except for 10.5 Mhz bandwidth which has slots of 18 ms.

TABLE 7

SBCH Channel Format Outline

Bandwidth (MHz)	Spreading Code Rate (MHz)	Epoch Length (ms)	Cycles/ Epoch N	Cycle Length (ms)	Slots/ Cycle M	Slot Length (ms)
7.0	5.824	5130	5	1026	54	19
10.0	8.320	3591	3	1197	63	19
10.5	8.512	3510	3	1170	65	18
14.0	11.648	2565	3	855	45	19
15.0	12.480	2394	2	1197	63	19

Sleep Cycle Slot #1 is always used for slow broadcast information. Slots #2 to #M−1 are used for paging groups unless extended slow broadcast information is inserted. The pattern of cycles and slots in one embodiment of the present invention run continuously at 16 kb/s.

Within each Sleep Cycle the SU powers-up the receiver and re-acquires the pilot code. It then achieves carrier lock to a sufficient precision for satisfactory demodulation and Viterbi decoding. The settling time to achieve carrier lock may be up to 3 Slots in duration. For example, an SU assigned to Slot #7 powers up the Receiver at the start of Slot #4. Having monitored its Slot the SU will have either recognized its Paging Address and initiated an access request, or failed to recognize its Paging Address in which case it reverts to the Sleep mode. Table 8 shows duty cycles for the different bandwidths, assuming a wake-up duration of 3 Slots.

TABLE 8

Sleep-Cycle Power Saving

Bandwidth (MHz)	Slots/Cycle	Duty Cycle
7.0	54	7.4%
10.0	63	6.3%
10.5	65	6.2%
14.0	45	8.9%
15.0	63	6.3%

Spreading code Tracking and AMF Detection in Multipath Channels

Spreading code Tracking

Three CDMA spreading code tracking methods in multipath fading environments are described which track the code phase of a received multipath spread-spectrum signal. The first is the prior art tracking circuit which simply tracks the spreading code phase with the highest detector output signal value, the second is a tracking circuit that tracks the median value of the code phase of the group of multipath signals,

and the third is the centroid tracking circuit which tracks the code-phase of an optimized, least mean squared weighted average of the multipath signal components. The following describes the algorithms by which the spreading code phase of the received CDMA signal is tracked.

A tracking circuit has operating characteristics that reveal the relationship between the time error and the control voltage that drives a Voltage Controlled Oscillator (VCO) of a spreading code phase tracking circuit. When there is a positive timing error, the tracking circuit generates a negative control voltage to offset the timing error. When there is a negative timing error, the tracking circuit generates a positive control voltage to offset the timing error. When the tracking circuit generates a zero value, this value corresponds to the perfect time alignment called the 'lock-point'. FIG. 3 shows the basic tracking circuit. Received signal r(t) is applied to matched filter **301**, which correlates r(t) with a local code-sequence c(t) generated by Code Generator **303**. The output signal of the matched filter x(t) is sampled at the sampler **302** to produce samples x[nT] and x[nT+T/2]. The samples x[nT] and x[nT+T/2] are used by a tracking circuit **304** to determine if the phase of the spreading code c(t) of the code generator **303** is correct. The tracking circuit **304** produces an error signal e(t) as an input to the code generator **303**. The code generator **303** uses this signal e(t) as an input signal to adjust the code-phase it generates.

In a CDMA system, the signal transmitted by the reference user is written in the low-pass representation as

$$s(t) = \sum_{k=-\infty}^{\infty} c_k P_{Tc}(t - kT_c) \tag{7}$$

where c_k represents the spreading code coefficients, $P_{Tc}(t)$ represents the spreading code chip waveform, and T_c is the chip duration. Assuming that the reference user is not transmitting data so that only the spreading code modulates the carrier. Referring to FIG. 3*c*, the received signal is

$$r(t) = \sum_{i=1}^{M} a_i s(t - \tau_i) \tag{8}$$

Here, a_i is due to fading effect of the multipath channel on the i-th path and τ_i is the random time delay associated with the same path. The receiver passes the received signal through a matched filter, which is implemented as a correlation receiver and is described below. This operation is done in two steps: first the signal is passed through a chip matched filter and sampled to recover the spreading code chip values, then this chip sequence is correlated with the locally generated code sequence.

FIG. 3*c* shows the chip matched filter **301**, matched to the chip waveform $P_{Tc}(i)$, and the sampler **302**. Ideally, the signal x(t) at the output terminal of the chip matched filter is

$$x(t) = \sum_{i=k}^{M} \sum_{k=-\infty}^{\infty} a_i c_k g(t - \tau_i - kT_c) \tag{9}$$

where

$$g(t) = P_{Tc}(t)^* h_R(t) \tag{10}$$

Here, $h_R(t)$ is the impulse response of the chip matched filter and '*' denotes convolution. The order of the summations can be rewritten as

$$x(t) = \sum_{k=-\infty}^{\infty} c_k f(t - kT_c) \tag{11}$$

where

$$f(t) = \sum_{i=1}^{M} a_i g(t - \tau_i) \tag{12}$$

In the multipath channel described above, the sampler samples the output signal of the matched filter to produce x(nT) at the maximum power level points of g(t). In practice, however, the waveform g(t) is severely distorted because of the effect of the multipath signal reception, and a perfect time alignment of the signals is not available.

When the multipath distortion in the channel is negligible and a perfect estimate of the timing is available, i.e., $a_1=1$, $\tau_1=0$, and $a_i=0$, i=2, . . . ,M, the received signal is r(t)=s(t). Then, with this ideal channel model, the output of the chip matched filter becomes

$$x(t) = \sum_{k=-\infty}^{\infty} c_k g(t - kT_c) \tag{13}$$

When there is multipath fading, however, the received spreading code chip value waveform is distorted, and has a number of local maxima that can change from one sampling interval to another depending on the channel characteristics.

For multipath fading channels with quickly changing channel characteristics, it is not practical to try to locate the maximum of the waveform f(t) in every chip period interval. Instead, a time reference may be obtained from the characteristics of f(t) that may not change as quickly. Three tracking methods are described based on different characteristics of f(t).

Prior Art Spreading Code Tracking Method

Prior art tracking methods include a code tracking circuit in which the receiver attempts to determine the timing of the maximum matched filter output value of the chip waveform occurs and sample the signal accordingly. However, in multipath fading channels, the receiver despread code waveform can have a number of local maxima, especially in a mobile environment. In the following, f(t) represents the received signal waveform of the spreading code chip convolved with the channel impulse response. The frequency response characteristic of f(t) and the maximum of this characteristic can change rather quickly making it impractical to track the maximum of f(t).

Define τ to be the time estimate that the tracking circuit calculates during a particular sampling interval. Also, define the following error function

$$\varepsilon = \begin{cases} \int_{\{t:|\tau-t|,\delta\}} f(t)dt, & |\tau - t| > \delta \\ \varepsilon = 0 & |\tau - t| < \delta \end{cases} \tag{14}$$

The tracking circuits of the prior art calculate a value of the input signal that minimizes the error ϵ. One can write

$$\min \varepsilon = 1 - \max_{\tau} \int_{t-\delta}^{\tau-\delta} f(t)dt \tag{15}$$

Assuming $f(\tau)$ has a smooth shape in the values given, the value of τ for which $f(\tau)$ is maximum minimizes the error ϵ, so the tracking circuit tracks the maximum point of f(t).

Median Weighted Value Tracking Method

The Median Weighted Tracking Method of one embodiment of the present invention, minimizes the absolute weighted error, defined as

$$\varepsilon = \int_{-\infty}^{\infty} |t - \tau| f(t) dt \tag{16}$$

This tracking method calculates the 'median' signal value of f(t) by collecting information from all paths, where $f(\tau)$ is as in equation 12. In a multipath fading environment, the waveform f(t) can have multiple local maxima, but only one median.

To minimize ϵ, take the derivative of equation (16) is taken with respect to τ and the result is equated to zero, which gives

$$\int_{-\infty}^{\tau} f(t)dt = \int_{\tau}^{\infty} f(t)dt \tag{17}$$

The value of τ that satisfies (17) is called the 'median' of f(t). Therefore, the Median Tracking Method of the present embodiment tracks the median of f(t). FIG. **4** shows an implementation of the tracking circuit based on minimizing the absolute weighted error defined above. The signal x(t) and its one-half chip offset version x(t+T/2) are sampled by the A/D **401** at a rate 1/T. The following equation determines the operating characteristic of the circuit in FIG. 4:

$$\varepsilon(\tau) = \sum_{n=1}^{2L} |f(\tau - nT/2)| - |f(\tau + nT/2)| \tag{18}$$

Tracking the median of a group of multipath signals keeps the received energy of the multipath signal components substantially equal on the early and late sides of the median point of the correct locally generated spreading code phase c_n. The tracking circuit consists of an A/D **401** which samples an input signal x(t) to form the half-chip offset samples. The half chip offset samples are alternatively grouped into even samples called an early set of samples $x(nT+\tau)$ and odd samples called a late set of samples $x(nT+(T/2)+\tau)$. The first correlation bank adaptive matched filter **402** multiplies each early sample by the spreading code phases c(n+1), c(n+2), . . . , c(n+L), where L is small compared to the code length and approximately equal to number of chips of delay between the earliest and latest multipath signal. The output of each correlator is applied to a respective first sum-and-dump bank **404**. The magnitudes of the output values of the L sum-and-dumps are calculated in the calculator **406** and then summed in summer **408** to give an output value proportional to the signal energy in the early multipath signals. Similarly, a second correlation bank adaptive matched filter **403** operates on the late samples, using code phases c(n−1), c(n−2), . . . , c(n−L), and each output signal is applied to a respective sum-and-dump circuit in an integrator **405**. The magnitudes of the L sum-and-dump output signals are calculated in calculator **407** and then summed in summer **409** to give a value for the late multipath signal energy. Finally, the subtractor **410** calculates the difference and produces error signal $\epsilon(\tau)$ of the early and late signal energy values.

The tracking circuit adjusts by means of error signal $\epsilon(\tau)$ the locally generated code phases c(t) to cause the difference between the early and late values to tend toward 0.

Centroid Tracking Method

The optimal spreading code tracking circuit of one embodiment of the present invention is called the squared weighted tracking (or centroid) circuit. Defining τ to denote the time estimate that the tracking circuit calculates, based on some characteristic of f(t), the centroid tracking circuit minimizes the squared weighted error defined as

$$\varepsilon = \int_{-\infty}^{\infty} |t - \tau|^2 f(t) dt \tag{19}$$

This function inside the integral has a quadratic form, which has a unique minimum. The value of τ that minimizes ϵ can be found by taking the derivative of the above equation with respect to τ and equating to zero, which gives

$$\int_{-\infty}^{\infty} (-2t + 2\tau) f(t) dt = 0 \tag{20}$$

Therefore, the value of τ that satisfies equation (21)

$$\tau - \frac{1}{\beta} \int_{-\infty}^{\infty} t f(t) dt = 0 \tag{21}$$

is the timing estimate that the tracking circuit calculates, where β is a constant value.

Based on these observations, a realization of an exemplary tracking circuit which minimizes the squared weighted error is shown in FIG. **5***a*. The following equation determines the error signal $\epsilon(\tau)$ of the centroid tracking circuit:

$$\varepsilon(\tau) = \sum_{n=1}^{2L} n[|f(\tau - nT/2)| - |f(\tau + nT/2)|] = 0 \tag{22}$$

The value that satisfies $\epsilon(\tau)=0$ is the perfect estimate of the timing.

The early and late multipath signal energy on each side of the centroid point are equal. The centroid tracking circuit shown in FIG. *5a* consists of an A/D converter **501** which samples an input signal x(t) to form the half-chip offset samples. The half chip offset samples are alternatively grouped as an early set of samples $x(nT+\tau)$ and a late set of samples $x(nT+(T/2)+\tau)$. The first correlation bank adaptive matched filter **502** multiplies each early sample and each late sample by the positive spreading code phases c(n+1), c(n+2), . . . , c(n+L), where L is small compared to the code length and approximately equal to number of chips of delay between the earliest and latest multipath signal. The output signal of each correlator is applied to a respective one of L sum-and-dump circuits of the first sum and dump bank **504**. The magnitude value of each sum-and-dump circuit of the sum and dump bank **504** is calculated by the respective

calculator in the calculator bank **506** and applied to a corresponding weighting amplifier of the first weighting bank **508**. The output signal of each weighting amplifier represents the weighted signal energy in a multipath component signal.

The weighted early multipath signal energy values are summed in sample adder **510** to give an output value proportional to the signal energy in the group of multipath signals corresponding to positive code phases which are the early multipath signals. Similarly, a second correlation bank adaptive matched filter **503** operates on the early and late samples, using the negative spreading code phases c(n−1), c(n−2), . . . , c(n−L); each output signal is provided to a respective sum-and-dump circuit of discrete integrator **505**. The magnitude value of the L sum-and-dump output signals are calculated by the respective calculator of calculator bank **507** and then weighted in weighting bank **509**. The weighted late multipath signal energy values are summed in sample adder **511** to give an energy value for the group of multipath signals corresponding to the negative code phases which are the late multipath signals. Finally, the adder **512** calculates the difference of the early and late signal energy values to produce error sample value $\epsilon\tau$).

The tracking circuit of FIG. *5a* produces error signal $\epsilon(\tau)$ which is used to adjust the locally generated code phase c(nT) to keep the weighted average energy in the early and late multipath signal groups equal. The embodiment shown uses weighting values that increase as the distance from the centroid increases. The signal energy in the earliest and latest multipath signals is probably less than the multipath signal values near the centroid. Consequently, the difference calculated by the adder **510** is more sensitive to variations in delay of the earliest and latest multipath signals.

Quadratic Detector for Tracking

In the new embodiment of the tracking method, the tracking circuit adjusts sampling phase to be "optimal" and robust to multipath. Let f(t) represent the received signal waveform as in equation 12 above. The particular method of optimizing starts with a delay locked loop with an error signal $\epsilon(\tau)$ that drives the loop. The function $\epsilon(\tau)$ must have only one zero at $\tau=\tau_0$ where τ_0 is optimal. The optimal form for $\epsilon(\tau)$ has the canonical form:

$$\varepsilon(\tau) = \int_{-\infty}^{\infty} w(t,\tau)|f(t)|^2 dt \tag{23}$$

where $w(t, \tau)$ is a weighting function relating f(t) to the error $\epsilon(\tau)$, and the relationship indicated by equation (24) also holds

$$\varepsilon(\tau+\tau_0) = \int_{-\infty}^{\infty} w(t,\tau+\tau_0)|f(t)|^2 dt \tag{24}$$

It follows from equation (24) that $w(t, \tau)$ is equivalent to $w(t-\tau)$. Considering the slope M of the error signal in the neighborhood of a lock point τ_0:

$$M = \left.\frac{d\varepsilon(\tau)}{d\tau}\right|_{\tau_0} = -\int_{-\infty}^{\infty} w'(t-\tau_0)g(t)dt \tag{25}$$

where $w'(t, \tau)$ is the derivative of $w(t, \tau)$ with respect to τ, and g(t) is the average of $|f(t)|^2$.

The error $\epsilon(\tau)$ has a deterministic part and a noise part. Let z denote the noise component in $\epsilon(\tau)$, then $|z|^2$ is the average noise power in the error function $\epsilon(\tau)$. Consequently, the optimal tracking circuit maximizes the ratio

$$F = \frac{M^2}{|z|^2} \tag{26}$$

The implementation of the Quadratic Detector is now described. The discrete error value e of an error signal $\epsilon(\tau)$ is generated by performing the operation

$$e = y^T B y \tag{27}$$

where the vector y represents the received signal components yi, i=0, 1, . . . L−1, as shown in FIG. *5b*. The matrix B is an L by L matrix and the elements are determined by calculating values such that the ratio F of equation (26) is maximized.

The Quadratic Detector described above may be used to implement the centroid tracking system described above with reference to FIG. *5a*. For this implementation, the vector y is the output signal of the sum and dump circuits **504**:

$$y=\{f(\tau-LT), f(\tau LT+T/2), f(\tau-(L-1)T), \ldots f(\tau), f(\tau+T/2), f(\tau+T), \ldots f(\tau+LT)\}$$

and the matrix B is set forth in table 9.

TABLE 9

B matrix for quadratic form of Centroid Tracking System

L	0	0	0	0	0	0	0	0	0	0
0	L − ½	0	0	0	0	0	0	0	0	0
0	0	L − 1	0	0	0	0	0	0	0	0
⋮	⋮	⋮	⋱	⋮	⋮	⋮	⋮	⋮	⋮	⋮
0	0	0	0	½	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	−½	0	0	0	0
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋱	⋮	⋮	⋮
0	0	0	0	0	0	0	0	−L + 1	0	0
0	0	0	0	0	0	0	0	0	−L + ½	0
0	0	0	0	0	0	0	0	0	0	−L

Determining the Minimum Value of L needed:

The value of L in the previous section determines the minimum number of correlators and sum-and-dump elements. L is chosen as small as possible without compromising the functionality of the tracking circuit.

The multipath characteristic of the channel is such that the received chip waveform f(t) is spread over QT_c seconds, or the multipath components occupy a time period of Q chips duration. The value of L chosen is L=Q. Q is found by measuring the particular RF channel transmission characteristics to determine the earliest and latest multipath component signal propagation delay. QT_c is the difference between the earliest and latest multipath component arrival time at a receiver.

Adaptive Vector Correlator

An embodiment of the present invention uses an adaptive vector correlator (AVC) to estimate the channel impulse response and to obtain a reference value for coherent combining of received multipath signal components. The described embodiment employs an array of correlators to

estimate the complex channel response affecting each multipath component. The receiver compensates for the channel response and coherently combines the received multipath signal components. This approach is referred to as maximal ratio combining.

Referring to FIG. **6**, the input signal x(t) to the system includes interference noise of other message channels, multipath signals of the message channels, thermal noise, and multipath signals of the pilots signal. The signal is provided to AVC **601** which, in the exemplary embodiment, includes a despreading means **602**, channel estimation means for estimating the channel response **604**, correction means for correcting a signal for effects of the channel response **603**, and adder **605**. The AVC despreading means **602** is composed of multiple code correlators, with each correlator using a different phase of the pilot code c(t) provided by the pilot code generator **608**. The output signal of this despreading means corresponds to a noise power level if the local pilot code of the despreading means is not in phase with the input code signal. Alternatively, it corresponds to a received pilot signal power level plus noise power level if the phases of the input pilot code and locally generated pilot code are the same. The output signals of the correlators of the despreading means are corrected for the channel response by the correction means **603** and are applied to the adder **605** which collects all multipath pilot signal power. The channel response estimation means **604** receives the combined pilot signal and the output signals of the despreading means **602**, and provides a channel response estimate signal, w(t), to the correction means **603** of the AVC, and the estimate signal w(t) is also available to the adaptive matched filter (AMF) described below. The output signal of the despreading means **602** is also provided to the acquisition decision means **606** which decides, based on a particular algorithm such as a sequential probability ratio test (SPRT), if the present output levels of the despreading circuits correspond to synchronization of the locally generated code to the desired input code phase. If the detector finds no synchronization, then the acquisition decision means sends a control signal a(t) to the local pilot code generator **608** to offset its phase by one or more chip period. When synchronization is found, the acquisition decision means informs tracking circuit **607**, which achieves and maintains a close synchronization between the received and locally generated code sequences.

An exemplary implementation of the Pilot AVC used to despread the pilot spreading code is shown in FIG. **7**. The described embodiment assumes that the input signal x(t) has been sampled with sampling period T to form samples x(nT+τ), and is composed of interference noise of other message channels, multipath signals of message channels, thermal noise, and multipath signals of the pilot code. The signal x(nT+τ) is applied to L correlators, where L is the number of code phases over which the uncertainty within the multipath signals exists. Each correlator **701**, **702**, **703** comprises a multiplier **704**, **705**, **706**, which multiples the input signal with a particular phase of the Pilot spreading code signal c((n+i)), and sum-and-dump circuits **708**, **709**, **710**. The output signal of each multiplier **704**, **705**, **706** is applied to a respective sum-and dump circuit **708**, **709**, **710** to perform discrete integration. Before summing the signal energy contained in the outputs of the correlators, the AVC compensates for the channel response and the carrier phase rotation of the different multipath signals. Each output of each sum-and-dump **708**, **709**, **710** is multiplied with a derotation phaser [complex conjugate of ep(nT)] from digital phase lock loop (DPLL) **721** by the respective multiplier **714**, **715**, **716** to account for the phase and frequency offset of the carrier signal. The Pilot Rake AMP calculates the weighting factors wk, k=1, . . . , L, for each multipath signal by passing the output of each multiplier **714**, **715**, **716** through a low pass filter (LPF) **711**, **712**, **713**. Each despread multipath signal is multiplied by its corresponding weighting factor in a respective multiplier **717**, **718**, **719**. The output signals of the multipliers **717**, **718**, **719** are summed in a master adder **720**, and the output signal p(nT) of the accumulator **720** consists of the combined despread multipath pilot signals in noise. The output signal p(nT) is also input to the DPLL **721** to produce the error signal ep(nT) for tracking of the carrier phase.

FIGS. **8***a* and **8***b* show alternate embodiments of the AVC which can be used for detection and multipath signal component combining. The message signal AVCs of FIGS. **8***a* and **8***b* use the weighting factors produced by the Pilot AVC to correct the message data multipath signals. The spreading code signal, c(nT) is the spreading code spreading sequence used by a particular message channel and is synchronous with the pilot spreading code signal The value L is the number of correlators in the AVC circuit.

The circuit of FIG. **8***a* calculates the decision variable Z which is given by

$$Z = w_1\sum_{i=1}^{N} x(iT+\tau)c(iT) + w_2\sum_{i=1}^{N} x(iT+\tau)c((i+1)T) + \cdots + w_L\sum_{i=1}^{L} x(iT+\tau) + c((i+L)T) \tag{28}$$

where N is the number of chips in the correlation window. Equivalently, the decision statistic is given by

$$\begin{aligned} Z &= x(T+\tau)\sum_{i=1}^{L} w_1 c(iT) + x(2T+\tau)\sum_{i=1}^{L} w_1 c((i+1)T) + \cdots + x(NT+\tau)\sum_{i=1}^{L} w_N c((i+N)T) \\ &= \sum_{k=1}^{N} x(kT-\tau)\sum_{i=1}^{L} w_k c((i+k-1)T) \end{aligned} \tag{29}$$

The alternative implementation that results from equation (29) is shown in FIG. **8***b*.

Referring to FIG. **8***a*, the input signal x(t) is sampled to form x(nT+τ), and is composed of interference noise of other message channels, multipath signals of message channels, thermal noise, and multipath signals of the pilot code. The signal x(nT+τ) is applied to L correlators, where L is the number of code phases over which the uncertainty within the multipath signals exists. Each correlator **801**, **802**, **803** comprises a multiplier **804**, **805**, **806**, which multiples the input signal by a particular phase of the message channel spreading code signal, and a respective sum-and-dump circuit **808**, **809**, **810**. The output signal of each multiplier **804**, **805**, **806** is applied to a respective sum-and dump circuit **808**, **809**, **810** which performs discrete integration. Before summing the signal energy contained in the output signals of the correlators, the AVC compensates for the different multipath signals. Each despread multipath signal and its corresponding weighting factor, which is obtained from the corresponding multipath weighting factor of the pilot AVC, are multiplied in a respective multiplier **817**, **818**, **819**. The output signals of multipliers **817**, **818**, **819** are summed in a master adder **820**, and the output signal z(nT) of the accu-

mulator **820** consists of sampled levels of a despread message signal in noise.

The alternative embodiment of the invention includes a new implementation of the AVC despreading circuit for the message channels which performs the sum-and-dump for each multipath signal component simultaneously. The advantage of this circuit is that only one sum-and dump circuit and one adder is necessary. Referring to FIG. *8b*, the message code sequence generator **830** provides a message code sequence to shift register **831** of length L. The output signal of each register **832, 833, 834, 835** of the shift register **831** corresponds to the message code sequence shifted in phase by one chip. The output value of each register **832, 833, 834, 835** is multiplied in multipliers **836, 837, 838, 839** with the corresponding weighting factor W_k, k=1, . . . , L obtained from the Pilot AVC. The output signals of the L multipliers **836, 837, 838, 839** are summed by the adding circuit **840**. The adding circuit output signal and the receiver input signal $x(nT+\tau)$ are then multiplied in the multiplier **841** and integrated by the sum-and-dump circuit **842** to produce message signal $z(nT)$.

A third embodiment of the adaptive vector correlator is shown in FIG. *8c*. The embodiment shown uses the least mean square (LMS) statistic to implement the vector correlator and determines the derotation factors for each multipath component from the received multipath signal. The AVC of FIG. *8c* is similar to the exemplary implementation of the Pilot AVC used to despread the pilot spreading code shown in FIG. 7. The digital phase locked loop **721** is replaced by the phase locked loop **850** having voltage controlled oscillator **851**, loop filter **852**, limiter **853**, and imaginary component separator **854**. The difference between the corrected despread output signal dos and an ideal despread output signal is provided by adder **855**, and the difference signal is a despread error value ide which is further used by the derotation circuits to compensate for errors in the derotation factors.

In a multipath signal environment, the signal energy of a transmitted symbol is spread out over the multipath signal components. The advantage of multipath signal addition is that a substantial portion of signal energy is recovered in an output signal from the AVC. Consequently, a detection circuit has an input signal from the AVC with a higher signal-to-noise ratio (SNR), and so can detect the presence of a symbol with a lower bit-error ratio (BER). In addition, measuring the output of the AVC is a good indication of the transmit power of the transmitter, and a good measure of the system's interference noise.

Adaptive Matched Filter

One embodiment of the current invention includes an Adaptive Matched Filter (AMF) to optimally combine the multipath signal components in a received spread spectrum message signal. The AMP is a tapped delay line which holds shifted values of the sampled message signal and combines these after correcting for the channel response. The correction for the channel response is done using the channel response estimate calculated in the AVC which operates on the Pilot sequence signal. The output signal of the AMF is the combination of the multipath components which are summed to give a maximum value. This combination corrects for the distortion of multipath signal reception. The various message despreading circuits operate on this combined multipath component signal from the AMF.

FIG. *8d* shows an exemplary embodiment of the AMF. The sampled signal from the A/D converter **870** is applied to the L-stage delay line **872**. Each stage of this delay line **872** holds the signal corresponding to a different multipath signal component. Correction for the channel response is applied to each delayed signal component by multiplying the component in the respective multiplier of multiplier bank **874** with the respective weighting factor $w_1, w_2, \ldots, W_L$ from the AVC corresponding to the delayed signal component. All weighted signal components are summed in the adder **876** to give the combined multipath component signal y(t).

The combined multipath component signal y(t) does not include the correction due to phase and frequency offset of the carrier signal. The correction for the phase and frequency offset of the carrier signal is made to y(t) by multiplying y(t) with carrier phase and frequency correction (derotation phasor) in multiplier **878**. The phase and frequency correction is produced by the AVC as described previously. FIG. *8d* shows the correction as being applied before the despreading circuits **880**, but alternate embodiments of the invention can apply the correction after the despreading circuits.

Method to Reduce Re-Acquisition Time with Virtual Location

One consequence of determining the difference in code phase between the locally generated pilot code sequence and a received spreading code sequence is that an approximate value for the distance between the base station and a subscriber unit can be calculated. If the SU has a relatively fixed position with respect to the RCS of the base station, the uncertainty of received spreading code phase is reduced for subsequent attempts at re-acquisition by the SU or RCS. The time required for the base station to acquire the access signal of a SU that has gone "off-hook" contributes to the delay between the SU going off-hook and the receipt of a dial tone from the PSTN. For systems that require a short delay, such as 150 msec for dial tone after off-hook is detected, a method which reduces the acquisition and bearer channel establishment time is desirable. One embodiment of the present invention uses such a method of reducing re-acquisition by use of virtual locating. Additional details of this technique are described in U.S. Patent Application entitled "VIRTUAL LOCATING OF A FIXED SUBSCRIBER UNIT TO REDUCE RE-ACQUISITION TIME" filed on even date herewith and incorporated herein by reference.

The RCS acquires the SU CDMA signal by searching only those received code phases corresponding to the largest propagation delay of the particular system. In other words, the RCS assumes that all SUs are at a predetermined, fixed distance from the RCS. The first time the SU establishes a channel- with the RCS, the normal search pattern is performed by the RCS to acquire the access channel. The normal method starts by searching the code phases corresponding to the longest possible delay, and gradually adjusts the search to the code phases with the shortest possible delay. However, after the initial acquisition, the SU can calculate the delay between the RCS and the SU by measuring the time difference between sending a short access message to the RCS and receiving an acknowledgment message, and using the received Global Pilot channel as a timing reference. The SU can also receive the delay value by having the RCS calculate the round trip delay difference from the code phase difference between the Global Pilot code generated at the RCS and the received assigned pilot sequence from the SU, and then sending the SU the value on a predetermined control channel. Once the round trip delay is known to the SU, the SU may adjust the code phase of the locally generated assigned pilot and spreading code sequences by adding the delay required to make the SU appear to the RCS to be at the predetermined fixed distance from the RCS. Although the method is explained for the

largest delay, a delay corresponding to any predetermined location in the system can be used.

A second advantage of the method of reducing re-acquisition by virtual locating is that a conservation in SU power use can be achieved. Note that a SU that is "powered down" or in a sleep mode needs to start the bearer channel acquisition process with a low transmit power level and ramp-up power until the RCS can receive its signal in order to minimize interference with other users. Since the subsequent re-acquisition time is shorter, and because the SU's location is relatively fixed in relation to the RCS, the SU can ramp-up transmit power more quickly because the SU will wait a shorter period of time before increasing transmit power. The SU waits a shorter period because it knows, within a small error range, when it should receive a response from the RCS if the RCS has acquired the SU signal.

The Spread Spectrum Communication System

The Radio Carrier Station (RCS)

The Radio Carrier Station (RCS) of the present invention acts as a central interface between the SU and the remote processing control network element, such as a Radio Distribution Unit (RDU). The interface to the RDU of the present embodiment follows the G.704 standard and an interface according to a modified version of DECT V5.1, but the present invention can support any interface that can exchange call control and traffic channels. The RCS receives information channels from the RDU including call control data, and traffic channel data such as, but not limited to, 32 kb/s ADPCM, 64 kb/s PCM, and ISDN, as well as system configuration and maintenance data. The RCS also terminates the CDMA radio interface bearer channels with SUs, which channels include both control data, and traffic channel data. In response to the call control data from either the RDU or a SU, the RCS allocates traffic channels to bearer channels on the RF communication link and establishes a communication connection between the SU and the telephone network through an RDU.

As shown in FIG. 9, the RCS receives call control and message information data into the MUXs **905**, **906** and **907** through interface lines **901**, **902** and **903**. Although E1 format is shown, other similar telecommunication formats can be supported in the same manner as described below. The MUXs shown in FIG. 9 may be implemented using circuits similar to that shown in FIG. 10. The MUX shown in FIG. 10 includes system clock signal generator **1001** consisting of phase locked oscillators (not shown) which generate clock signals for the Line PCM highway **1002** (which is part of PCM Highway **910**), and high speed bus (HSB) **970**; and the MUX Controller **1010** which synchronizes the system clock **1001** to interface line **1004**. It is contemplated that the phase lock oscillators can provide timing signals for the RCS in the absence of synchronization to a line. The MUX Line Interface **1011** separates the call control data from the message information data. Referring to FIG. 9, each MUX provides a connection to the Wireless Access Controller (WAC) **920** through the PCM highway **910**. The MUX controller **1010** also monitors the presence of different tones present in the information signal by means of tone detector **1030**.

Additionally, the MUX Controller **1010** provides the ISDN D channel network signaling locally to the RDU. The MUX line interface **1011**, such as a FALC **54**, includes an E1 interface **1012** which consists of a transmit connection pair (not shown) and a receive connection pair (not shown) of the MUX connected to the RDU or Central Office (CO) ISDN Switch at the data rate of 2.048 Mbps. The transmit and receive connection pairs are connected to the E1 interface **1012** which translates differential tri-level transmit/receive encoded pairs into levels for use by the Framer **1015**. The line interface **1011** uses internal phase-locked-loops (not shown) to produce E1-derived 2.048 MHz, and 4.096 MHz clocks as well as an 8 KHz frame-sync pulse. The line interface can operate in clock-master or clock-slave mode. While the exemplary embodiment is shown as using an E1 Interface, it is contemplated that other types of telephone lines which convey multiple calls may be used, for example, T1 lines or lines which interface to a Private Branch Exchange (PBX).

The line interface framer **1015** frames the data streams by recognizing the framing patterns on channel-1 (time-slot 0) of the incoming line, and inserts and extracts service bits, generates/checks line service quality information.

As long as a valid E1 signal appears at the E1 Interface **1012**, the FALC **54**, recovers a 2.048 MHz PCM clock signal from the E1 line. This clock, via System Clock **1001**, is used system wide as a PCM Highway Clock signal. If the E1 Line fails, the FALC **54** continues to deliver a PCM Clock derived from an oscillator signal o(t) connected to the sync input (not shown) of the FALC **54**. This PCM Clock serves the RCS system until another MUX with an operational E1 line assumes responsibility for generating the system clock signals.

The framer **1015** generates a Received Frame Sync Pulse, which in turn can be used to trigger the PCM Interface **1016** to transfer data onto the line PCM Highway **1002** and into the RCS System for use by other elements. Since all E1 lines are frame synchronized, all Line PCM Highways are also frame synchronized. From this 8 kHz PCM Sync pulse, the system clock signal generator **1001** of the MUX uses a Phase Locked Loop (not shown) to synthesize the PNx2 clock [e.g., 15.96 MHz)($W_0(t)$]. The frequency of this clock signal is different for different transmission bandwidths, as described in Table 7.

The MUX includes a MUX Controller **1010**, such as a 25 MHz Quad Integrated Communications Controller, containing a microprocessor **1020**, program memory **1021**, and Time Division Multiplexer (TDM) **1022**. The TDM **1022** is coupled to receive the signal provided by the Framer **1015**, and extracts information placed in time slots 0 and 16. The extracted information governs how the MUX controller **1010** processes the Link- Access Protocol-D (LAPD) data link. The call control and bearer modification messages, such as those defined as V5.1 Network layer messages, are either passed to the WAC, or used locally by the MUX controller **1010**.

The RCS Line PCM Highway **1002** is connected to and originates with the Framer **1015** through PCM Interface **1016**, and comprises of a 2.048 MHz stream of data in both the transmit and receive direction. The RCS also contains a High Speed Bus (HSB) **970** which is the communication link between the MUX, WAC, and MIUs. The HSB **970** supports a data rate of, for example, 100 Mbit/sec. Bach of the MUX, WAC, and MIU access the HSB using arbitration. The RCS of the present invention also can include several MUXs requiring one board to be a "master" and the rest "slaves". Details on the implementation of the HSB may be found in a U.S. patent application entitled PARALLEL PACKETIZED INTERMODULE ARBITRATED HIGH SPEED CONTROL AND DATA BUS, filed on even date herewith, which is hereby incorporated by reference.

Referring to FIG. 9, the Wireless Access Controller (WAC) 920 is the RCS system controller which manages call control functions and interconnection of data streams between the MUXs 905, 906, 907, Modem Interface Units (MIUs) 931, 932, 933. The WAC 920 also controls and monitors other RCS elements such as the VDC 940, RF 950, and Power Amplifiers 960. The WAC 920 as shown in FIG. 11, allocates bearer channels to the modems on each MIU 931, 932, 933 and allocates the message data on line PCM Highway 910 from the MUXs 905, 906, 907 to the modems on the MIUs 931, 932, 933. This allocation is made through the System PCM Highway 911 by means of a time slot interchange on the WAC 920. If more than one WAC is present for redundancy purposes, the WACs determines the Master-Slave relationship with a second WAC. The WAC 920 also generates messages and paging information responsive to call control signals from the MUXs 905, 906, 907 received from a remote processor, such as an RDU; generates Broadcast Data which is transmitted to the MIU master modem 934; and controls the generation by the MIU MM 934 of the Global system Pilot spreading code sequence. The WAC 920 also is connected to an external Network Manager (NM) 980 for craftperson or user access.

Referring to FIG. 11, the WAC includes a time-slot interchanger (TSI) 1101 which transfers information from one time slot in a Line PCM Highway or System PCM Highway to another time slot in either the same or different Line PCM Highway or System PCM Highway. The TSI 1101 is connected to the WAC controller 1111 of FIG. 11 which controls the assignment or transfer of information from one time slot to another time slot and stores this information in memory 1120. The exemplary embodiment of the invention has four PCM Highways 1102, 1103, 1104, 1105 connected to the TSI. The WAC also is connected to the HSB 970, through which WAC communicates to a second WAC (not shown), to the MUXs and to the MIUs.

Referring to FIG. 11, the WAC 920 includes a WAC controller 1111 employing, for example, a microprocessor 1112, such as a Motorola MC68040 and a communications processor 1113, such as the Motorola MC68360 QUICC communications processor, and a clock oscillator 1114 which receives a clock synch signal wo(t) from the system clock generator. The clock generator is located on a MUX (not shown) to provide timing to the WAC controller 1111. The WAC controller 1111 also includes memory 1120 including Flash Prom 1121 and SRAM memory 1122. The Flash Prom 1121 contains the program code for the WAC controller 1111, and is reprogrammable for new software programs downloaded from an external source. The SRAM 1122 is provided to contain the temporary data written to and read from memory 1120 by the WAC controller 1111.

A low speed bus 912 is connected to the WAC 920 for transferring control and status signals between the RF Transmitter/Receiver 950, VDC 940, RF 950 and Power Amplifier 960 as shown in FIG. 9. The control signals are sent from the WAC 920 to enable or disable the RF Transmitters/Receiver 950 or Power amplifier 960, and the status signals are sent from the RF Transmitters/Receiver 950 or Power amplifier 960 to monitor the presence of a fault condition.

Referring to FIG. 9, the exemplary RCS contains at least one MIU 931, which is shown in FIG. 12 and now described in detail. The MIU of the exemplary embodiment includes six CDMA modems, but the invention is not limited to this number of modems. The MIU includes a System PCM Highway 1201 connected to each of the CDMA Modems 1210, 1211, 1212, 1215 through a PCM Interface 1220, a Control Channel Bus 1221 connected to MIU controller 1230 and each of the CDMA Modems 1210, 1211, 1212, 1213, an MIU clock signal generator (CLK) 1231, and a modem output combiner 1232. The MIU provides the RCS with the following functions: the MIU controller receives CDMA Channel Assignment Instructions from the WAC and assigns a modem to a user information signal which is applied to the line interface of the MUX and a modem to receive the CDMA channel from the SU; it also combines the CDMA Transmit Modem Data for each of the MIU CDMA modems; multiplexes I and Q transmit message data from the CDMA modems for transmission to the VDC; receives Analog I and Q receive message data from the VDC; distributes the I and Q data to the CDMA modems; transmits and receives digital AGC Data; distributes the AGC data to the CDMA modems; and sends MIU Board Status and Maintenance Information to the WAC 920.

The MIU controller 1230 of the exemplary embodiment of the present invention contains one communication microprocessor 1240, such as the MC68360 "QUICC" Processor, and includes a memory 1242 having a Flash Prom memory 1243 and a SRAM memory 1244. Flash Prom 1243 is provided to contain the program code for the Microprocessors 1240, and the memory 1243 is downloadable and reprogrammable to support new program versions. SRAM 1244 is provided to contain the temporary data space needed by the MC68360 Microprocessor 1240 when the MIU controller 1230 reads or writes data to memory

The MIU CLK circuit 1231 provides a timing signal to the MIU controller 1230, and also provides a timing signal to the CDMA modems. The MIU CLK circuit 1231 receives and is synchronized to the system clock signal wo(t). The controller clock signal generator 1213 also receives and synchronizes to the spreading code clock signal pn(t) which is distributed to the CDMA modems 1210, 1211, 1212, 1215 from the MUX.

The RCS of the present embodiment includes a System Modem 1210 contained on one MIU. The System Modem 1210 includes a Broadcast spreader (not shown) and a Pilot Generator (not shown). The Broadcast Modem provides the broadcast information used by the exemplary system, and the broadcast message data is transferred from the MIU controller 1230 to the System Modem 1210. The System Modem also includes four additional modems (not shown) which are used to transmit the signals CT1 through CT4 and AX1 through AX4. The System Modem 1210 provides unweighted I and Q Broadcast message data signals which are applied to the VDC. The VDC adds the Broadcast message data signal to the MIU CDMA Modem Transmit Data of all CDMA modems 1210, 1211, 1212, 1215, and the Global Pilot signal.

The Pilot Generator (PG) 1250 provides the Global Pilot signal which is used by the present invention, and the Global Pilot signal is provided to the CDMA modems 1210, 1211, 1212, 1215 by the MIU controller 1230. However, other embodiments of the present invention do not require the MIU controller to generate the Global Pilot signal, but include a Global Pilot signal generated by any form of CDMA Code Sequence generator. In the described embodiment of the invention, the unweighted I and Q Global Pilot signal is also sent to the VDC where it is assigned a weight, and added to the MIU CDMA Modem transmit data and Broadcast message data signal.

System timing in the RCS is derived from the E1 interface. There are four MUXs in an RCS, three of which (905, 906 and 907) are shown in FIG. 9. Two MUXs are located

on each chassis. One of the two MUXs on each chassis is designated as the master, and one of the masters is designated as the system master. The MUX which is the system master derives a 2.048 Mhz PCM clock signal from the E1 interface using a phase locked loop (not shown). In turn, the system master MUX divides the 2.048 Mhz PCM clock signal in frequency by 16 to derive a 128 KHz reference clock signal. The 128 KHz reference clock signal is distributed from the MUX that is the system master to all the other MUXs. In turn, each MUX multiplies the 128 KHz reference clock signal in frequency to synthesize the system clock signal which has a frequency that is twice the frequency of the PN-clock signal. The MUX also divides the 128 KHz clock signal in frequency by 16 to generate the 8 KHz frame synch signal which is distributed to the MIUs. The system clock signal for the exemplary embodiment has a frequency of 11.648 Mhz for a 7 MHz bandwidth CDMA channel Each MUX also divides the system clock signal in frequency by 2 to obtain the PN-clock signal and further divides the PN-clock signal in frequency by 29 877 120 (the PN sequence length) to generate the PN-synch signal which indicates the epoch boundaries. The PN-synch signal from the system master MUX is also distributed to all MUXs to maintain phase alignment of the internally generated clock signals for each MUX. The PN-synch signal and the frame synch signal are aligned. The two MUXs that are designated as the master MUXs for each chasis then distribute both the system clock signal and the PN-clock signal to the MIUs and the VDC.

The PCM Highway Interface **1220** connects the System PCM Highway **911** to each CDMA Modem **1210**, **1211**, **1212**, **1215**. The WAC controller transmits Modem Control information, including traffic message control signals for each respective user information signal, to the MIU controller **1230** through the HSB **970**. Each CDMA Modem **1210**, **1211**, **1212**, **1215** receives a traffic message control signal, which includes signaling information, from the MIU controller **1111**. Traffic message control signals also include call control (CC) information and spreading code and despreading code sequence information.

The MIU also includes the Transmit Data Combiner **1232** which adds weighted CDMA modem transmit data including In-phase (I) and Quadrature (Q) modem transmit data from the CDMA modems **1210**, **1211**, **1212**, **1215** on the MIU. The I modem transmit data is added separately from the Q modem transmit data. The combined I and Q modem transmit data output signal of the Transmit Data Combiner **1232** is applied to the I and Q multiplexer **1233** that creates a single CDMA transmit message channel composed of the I and Q modem transmit data multiplexed into a digital data stream.

The Receiver Data Input Circuit (RDI) **1234** receives the Analog Differential I and Q Data from the Video Distribution Circuit (VDC) **940** shown in FIG. **9** and distributes Analog Differential I and Q Data to each of the CDMA Modems **1210**, **1211**, **1212**, **1215** of the MIU. The Automatic Gain Control Distribution Circuit (AGC) **1235** receives the AGC Data signal from the VDC and distributes the AGC Data to each of the CDMA Modems of the MIU. The TRL circuit **1233** receives the Traffic lights information and similarly distributes the Traffic light data to each of the Modems **1210**, **1211**, **1212**, **1215**.

The CDMA Modem

The CDMA modem provides for generation of CDMA spreading code sequences and synchronization between

transmitter and receiver. It also provides four full duplex channels (TR0, TR1, TR2, TR3) programmable to 64, 32, 16, and 8 ksym/sec. each, for spreading and transmission at a specific power level. The CDMA modem measures the received signal strength to allow Automatic Power Control, it generates and transmits pilot signals, and encodes and decodes using the signal for forward error correction (FEC). The modem in an SU also performs transmitter spreading code pulse shaping using an FIR filter. The CDMA modem is also used by the Subscriber Unit (SU), and in the following discussion those features which are used only by the SU are distinctly pointed out. The operating frequencies of the CDMA modem are given in Table 10.

TABLE 10

Operating Frequencies

Bandwidth (MHz)	Chip Rate (MHz)	Symbol Rate (KHz)	Gain (Chips/Symbol)
7	5.824	64	91
10	8.320	64	130
10.5	8.512	64	133
14	11.648	64	182
15	12.480	64	195

Each CDMA modem **1210**, **1211**, **1212**, **1215** of FIG. **12**, and as shown in FIG. **13**, is composed of a transmit section **1301** and a receive section **1302**. Also included in the CDMA modem is a control center **1303** which receives control messages CNTRL from the external system. These messages are used, for example, to assign particular spreading codes, activate the spreading or despreading, or to assign transmission rates. In addition, the CDMA modem has a code generator means **1304** used to generate the various spreading and despreading codes used by the CDMA modem. The transmit section **1301** is for transmitting the input information and control signals $m_i(t)$, i=1,2, . . . I as spread-spectrum processed user information signals $sc_j(t)$, j=1,2, . . . J. The transmit section **1301** receives the global pilot code from the code generator **1304** which is controlled by the control means **1303**. The spread spectrum processed user information signals are ultimately added to other similar processed signals and transmitted as CDMA channels over the CDMA RF forward message link, for example to the SUs. The receive section **1302** receives CDMA channels as r(t) and despreads and recovers the user information and control signals $rc_k(t)$, k=1,2, . . . K transmitted over the CDMA RF reverse message link, for example to the RCS from the SUs.

CDMA Modem Transmitter Section

Referring to FIG. **14**, the code generator means **1304** includes Transmit Timing Control Logic **1401** and spreading code PN-Generator **1402**, and the Transmit Section **1301** includes Modem Input Signal Receiver (MISR) **1410**, Convolution Encoders **1411**, **1412**, **1413**, **1414**, Spreaders **1420**, **1421**, **1422**, **1423**, **1424**, and Combiner **1430**. The Transmit Section **1301** receives the message data channels MESSAGE, convolutionally encodes each message data channel in the respective convolutional encoder **1411**, **1412**, **1413**, **1414**, modulates the data with random spreading code sequence in the respective spreader **1420**, **1421**, **1422**, **1423**, **1424**, and combines modulated data from all channels, including the pilot code received in the described embodiment from the code generator, in the combiner **1430** to generate I and Q components for RF transmission. The Transmitter Section **1301** of the present embodiment sup-

ports four (TR0, TR1, TR2, TR3) 64, 32, 16, 8 kb/s programmable channels. The message channel data is a time multiplexed signal received from the PCM highway 1201 through PCM interface 1220 and input to the MISR 1410.

FIG. 15 is a block diagram of an exemplary MISR 1410. For the exemplary embodiment of the present invention, a counter is set by the 8 KHz frame synchronization signal MPCMSYNC and is incremented by 2.048 MHz MPCM-CLK from the timing circuit 1401. The counter output is compared by comparator 1502 against TRCFG values corresponding to slot time location for TR0, TR1, TR2, TR3 message channel data; and the TRCFG values are received from the MIU Controller 1230 in MCTRL. The comparator sends count signal to the registers 1505, 1506, 1507 and 1508 which clocks message channel data into buffers 1510, 1511, 1512, 1513 using the TXPCNCLK timing signal derived from the system clock. The message data is provided from the signal MSGDAT from the PCM highway signal MESSAGE when enable signals TR0EN, TR1EN, TR2EN and TR3EN from Timing Control Logic 1401 are active. In further embodiments, MESSAGE may also include signals that enable registers depending upon an encryption rate or data rate. If the counter output is equal to one of the channel location addresses, the specified transmit message data in registers 1510, 1511, 1512, 1513 are input to the convolutional encoders 1411, 1412, 1413, 1414 shown in FIG. 14.

The convolutional encoder enables the use of Forward Error Correction (FEC) techniques, which are well known in the art. FEC techniques depend on introducing redundancy in generation of data in encoded form. Encoded data is transmitted and the redundancy in the data enables the receiver decoder device to detect and correct errors. One embodiment of the present invention employs convolutional encoding. Additional data bits are added to the data in the encoding process and are the coding overhead. The coding rate is expressed as the ratio of data bits transmitted to the total bits (code data+redundant data) transmitted and is called the rate "R" of the code.

Convolution codes are codes where each code bit is generated by the convolution of each new uncoded bit with a number of previously coded bits. The total number of bits used in the encoding process is referred to as the constraint length, "K", of the code. In convolutional coding, data is clocked into a shift register of K bits length so that an incoming bit is clocked into the register, and it and the existing K−1 bits are convolutionally encoded to create a new symbol. The convolution process consists of creating a symbol consisting of a module-2 sum of a certain pattern of available bits, always including the first bit and the last bit in at least one of the symbols.

FIG. 16 shows the block diagram of a K=7, R=½ convolution encoder suitable for use as the encoder 1411 shown in FIG. 14. This circuit encodes the TR0 Channel as used in one embodiment of the present invention. Seven-Bit Register 1601 with stages Q1 through Q7 uses the signal TXPNCLK to clock in TR0 data when the TR0EN signal is asserted. The output value of stages Q1, Q2, Q3, Q4, Q6, and Q7 are each combined using EXCLUSIVE-OR Logic 1602, 1603 to produce respective I and Q channel FEC data for the TR0 channel FECTR0DI and FECTR0DQ.

Two output symbol streams FECTR0DI and FECTR0DQ are generated. The FECTR0DI symbol stream is generated by EXCLUSIVE OR Logic 1602 of shift register outputs corresponding to bits 6, 5, 4,3, and 0, (Octal 171) and is designed as In phase component "I" of the transmit message channel data. The symbol stream FECTR0DQ is likewise generated by EXCLUSIVE-OR logic 1603 of shift register outputs from bits 6, 4 3, 1 and 0, (Octal 133) and is designated as Quadrature component "Q" of the transmit message channel data. Two symbols are transmitted to represent a single encoded bit creating the redundancy necessary to enable error correction to take place on the receiving end.

Referring to FIG. 14, the shift enable clock signal for the transmit message channel data is generated by the Control Timing Logic 1401. The convolutionally encoded transmit message channel output data for each channel is applied to the respective spreader 1420, 1421, 1422, 1423, 1424 which multiplies the transmit message channel data by its preassigned spreading code sequence from code generator 1402. This spreading code sequence is generated by control 1303 as previously described, and is called a random pseudonoise signature sequence (PN-code).

The output signal of each spreader 1420, 1421, 1422, 1423, 1424 is a spread transmit data channel. The operation of the spreader is as follows: the spreading of channel output (I+jQ) multiplied by a random sequence (PNI+jPNQ) yields the In-phase component I of the result being composed of (I xor PNI) and (−Q xor PNQ). Quadrature component Q of the result is (Q xor PNI) and (I xor PNQ). Since there is no channel data input to the pilot channel logic (I=1, Q values are prohibited), the spread output signal for pilot channels yields the respective sequences PNI for I component and PNQ for Q component.

The combiner 1430 receives the I and Q spread transmit data channels and combines the channels into an I modem transmit data signal (TXIDAT) and a Q modem transmit data signal (TXQDAT). The I-spread transmit data and the Q spread transmit data are added separately.

For an SU, the CDMA modem Transmit Section 1301 includes the FIR filters to receive the I and Q channels from the combiner to provide pulse shaping, close-in spectral control and x/sin (x) correction for the transmitted signal. Separate but identical FIR filters receive the I and Q spread transmit data streams at the chipping rate, and the output signal of each of the filters is at twice the chipping rate. The exemplary FIR filters are 28 tap even symmetrical filters, which upsample (interpolate) by 2. The upsampling occurs before the filtering, so that 28 taps refers to 28 taps at twice the chipping rate, and the upsampling is accomplished by setting every other sample a zero. Exemplary coefficients are shown in Table 11.

TABLE 11

Coefficient Values

Coeff.No.:	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Value:	3	−11	−34	−22	19	17	−32	−19	52	24	−94	−31	277	468
Coeff.No.	14	15	16	17	18	19	20	21	22	24	25	26	27	
Value	277	−31	−94	24	52	−19	−32	17	19	−22	−34	−11	3	

CDMA Modem Receiver Section

Referring to FIGS. 9 and 12, the RF receiver **950** of the present embodiment accepts analog input I and Q CDMA channels, which are transmitted to the CDMA modems **1210**, **1211**, **1212**, **1215** through the MIUs **931**, **932**, **933** from the VDC **940**. These I and Q CMDA channel signals are sampled by the CDMA modem receive section **1302** (shown in FIG. 13) and converted to I and Q digital receive message signal using an Analog to Digital (A/D) converter **1730**, shown in FIG. 17. The sampling rate of the A/D converter of the exemplary embodiment of the present invention is equivalent to the despreading code rate. The I and Q digital receive message signals are then despread with correlators using six different complex spreading code sequences corresponding to the despreading code sequences of the four channels (**TR0**, **TR1**, **TR2**, **TR3**), APC information and the pilot code.

Time synchronization of the receiver to the received signal is separated into two phases; there is an initial acquisition phase and then a tracking phase after the signal timing has been acquired. The initial acquisition is done by shifting the phase of the locally generated pilot code sequence relative to the received signal and comparing the output of the pilot despreader to a threshold. The method used is called sequential search. Two thresholds (match and dismiss) are calculated from the auxiliary despreader. Once the signal is acquired, the search process is stopped and the tracking process begins. The tracking process maintains the code generator **1304** (shown in FIGS. 13 and 17) used by the receiver in synchronization with the incoming signal. The tracking loop used is the Delay-Locked Loop (DLL) and is implemented in the acquisition & track **1701** and the IPM **1702** blocks of FIG. 17.

In FIG. 13, the modem controller **1303** implements the Phase Lock Loop (PLL) as a software algorithm in SW PILL logic **1724** of FIG. 17 that calculates the phase and frequency shift in the received signal relative to the transmitted signal. The calculated phase shifts are used to derotate the phase shifts in rotate and combine blocks **1718**, **1719**, **1720**, **1721** of the multipath data signals for combining to produce output signals corresponding to receive channels TR0', TR1', TR2', TR3'. The data is then Viterbi decoded in Viterbi Decoders **1713**, **1714**, **1715**, **1716** to remove the convolutional encoding in each of the received message channels.

FIG. 17 indicates that the Code Generator **1304** provides the code sequences $Pn_i(t)$, i=1,2, . . . I used by the receive channel despreaders **1703**, **1704**, **1705**, **1706**, **1707**, **1708**, **1709**. The code sequences generated are timed in response to the SYNK signal of the system clock signal and are determined by the CCNTRL signal from the modem controller **1303** shown in FIG. 13. Referring to FIG. 17, the CDMA modem receiver section **1302** includes Adaptive Matched Filter (AMF) **1710**, Channel despreaders **1703**, **1704**, **1705**, **1706**, **1707**, **1708**, **1709**, Pilot AVC **1711**, Auxiliary AVC **1712**, Viterbi decoders **1713**, **1714**, **1715**, **1716**, Modem output interface (MOI) **1717**, Rotate and Combine logic **1718**, **1719**, **1720**, **1721**, AMF Weight Generator **1722**, and Quantile Estimation logic **1723**.

In another embodiment of the invention, the CDMA modem receiver also includes a Bit error Integrator to measure the BER of the channel and idle code insertion logic between the Viterbi decoders **1713**, **1714**, **1715**, **1716** and the MOI **1717** to insert idle codes in the event of loss of the message data.

The Adaptive Matched Filter (AMP) **1710** resolves multipath interference introduced by the air channel. The exemplary AMF **1710** uses an 11 stage complex FIR filter as shown in FIG. 18. The received I and Q digital message signals are received at the register **1820** from the A/D **1730** of FIG. 17 and are multiplied in multipliers **1801**, **1802**, **1803**, **1810**, **1811** by I and Q channel weights W1 to W11 received from AMF weight generator **1722** of FIG. 17. In the exemplary embodiment, the A/D **1730** provides the I and Q digital receive message signal data as 2's complement values, 6 bits for I and 6 bits for Q which are clocked through an 11 stage shift register **1820** responsive to the receive spreading-code clock signal RXPNCLK. The signal RXPNCLK is generated by the timing section **1401** of code generation logic **1304**. Each stage of the shift register is tapped and complex multiplied in the multipliers **1801**, **1802**, **1803**, **1810**, **1811** by individual (6-bit I and 6-bit Q) weight values to provide 11 tap-weighted products which are summed in adder **1830**, and limited to 7-bit I and 7-bit Q values.

The CDMA modem receive section **1302** (shown in FIG. 13) provides independent channel despreaders **1703**, **1704**, **1705**, **1706**, **1707**, **1708**, **1709** (shown in FIG. 17) for despreading the message channels. The described embodiment despreads 7 message channels, each despreader accepting a 1-bit I b 1-bit Q despreading code signal to perform a complex correlation of this code against a 8-bit I by 8-bit Q data input. The 7 despreaders correspond to the 7 channels: Traffic Channel **0** (TR0'), TR1', T2'T3', AUX (a spare channel), Automatic Power Control (APC) and pilot (PLT).

The Pilot AVC **1711** shown in FIG. 19 receives the I and Q Pilot Spreading code sequence values PCI and PCQ into shift register **1920** responsive to the timing signal RXPNCLK, and includes 11 individual despreaders **1901** through **1911** each correlating the I and Q digital receive message signal data with a one chip delayed version of the same pilot code sequence. Signals OE1, OE2, . . . OE11 are used by the modem control **1303** to enable the despreading operation. The output signals of the despreaders are combined in combiner **1920** forming correlation signal DSPRDAT of the Pilot AVC **1711**, which is received by the ACQ & Track logic **1701** (shown in FIG. 17), and ultimately by modem controller **1303** (shown in FIG. 13). The ACQ & Track logic **1701** uses the correlation signal value to determine if the local receiver is synchronized with its remote transmitter.

The Auxiliary AVC **1712** also receives the I and Q digital receive message signal data and, in the described embodiment, includes four separate despreaders **2001**, **2002**, **2003**, **2004** as shown in FIG. 20. Each despreader receives and correlates the I and Q digital receive message data with delayed versions of the same despreading code sequence PARI and PARQ which are provided by code generator **1304** input to and contained in shift register **2020**. The output signals of the despreaders **2001**, **2002**, **2003**, **2004** are combined in combiner **2030** which provides noise correlation signal ARDSPRDAT. The auxiliary AVC spreading code sequence does not correspond to any transmit spreading code sequence of the system. Signals OE1, OE2, . . . OE4 are used by the modem control **1303** to enable the despreading operation. The Auxiliary AVC **1712** provides a noise correlation signal ARDSPRDAT from which quantile estimates are calculated by the Quantile estimator **1733**, and provides a noise level measurement to the ACQ & Track logic **1701** (shown in FIG. 17) and modem controller **1303** (shown in FIG. 13).

Each despread channel output signal corresponding to the received message channels TR0', TR1', TR2', and TR3' is

input to a corresponding Viterbi decoder **1713**, **1714**, **1715**, **1716** shown in FIG. **17** which performs forward error correction on convolutionally encoded data. The Viterbi decoders of the exemplary embodiment have a constraint length of K=7 and a rate of R=½. The decoded despread message channel signals are transferred from the CDMA modem to the PCM Highway **1201** through the MOI **1717** The operation of the MOI is essentially the same as the operation of the MISR of the transmit section **1301** (shown in FIG. 13) except in reverse.

The CDMA modem receiver section **1302** implements several different algorithms during different phases of the acquisition, tracking and despreading of the receive CDMA message signal.

When the received signal is momentarily lost (or severely degraded) the idle code insertion algorithm inserts idle codes in place of the lost or degraded receive message data to prevent the user from hearing loud noise bursts on a voice call. The idle codes are sent to the MOI **1717** (shown in FIG. **17**) in place of the decoded message channel output signal from the Viterbi decoders **1713**, **1714**, **1715**, **1716**. The idle code used for each traffic channel is programmed by the Modem Controller **1303** by writing the appropriate pattern IDLE to the MOI, which in the present embodiment is a 8 bit word for a 64 kb/s stream, 4 bit word for a 32 kb/s stream.

Modem Algorithms for Acquisition and Tracking of Received Pilot Signal

The acquisition and tracking algorithms are used by the receiver to determine the approximate code phase of a received signal, synchronize the local modem receiver despreaders to the incoming pilot signal, and track the phase of the locally generated pilot code sequence with the received pilot code sequence. Referring to FIGS. **13** and **17**, the algorithms are performed by the Modem controller **1303**, which provides clock adjust signals to code generator **1304**. These adjust signals cause the code generator for the despraders to adjust locally generated code sequences in response to measured output values of the Pilot Rake **1711** and Quantile values from quantile estimators **1723B**. Quantile values are noise statistics measured from the In-phase and Quadrature channels from the output values of the AUX Vector Correlator **1712** (shown in FIG. **17**). Synchronization of the receiver to the received signal is separated into two phases; an initial acquisition phase and a tracking phase The initial acquisition phase is accomplished by clocking the locally generated pilot spreading code sequence at a higher or lower rate than the received signal's spreading code rate, sliding the locally generated pilot spreading code sequence and performing sequential probability ratio test (SPRT) on the output of the Pilot Vector correlator **1711**. The tracking phase maintains the locally generated spreading code pilot sequence in synchronization with the incoming pilot signal. Details of the quantile estimators **1723B** may be found in U.S. patent application Ser. No. 08/218,198 entitled "ADAPTIVE POWER CONTROL FOR A SPREAD SPECTRUM COMMUNICATIONS SYSTEM" which is incorporated by reference herein for its teachings on adaptive power control systems.

The SU cold acquisition algorithm is used by the SU CDMA modem when it is first powered up, and therefore has no knowledge of the correct pilot spreading code phase, or when an SU attempts to reacquire synchronization with the incoming pilot signal but has taken an excessive amount of time. The cold acquisition algorithm is divided into two sub-phases. The first subphase consists of a search over the length 233415 code used by the FBCH. Once this sub-code phase is acquired, the pilot's 233415×128 length code is known to within an ambiguity of 128 possible phases. The second subphase is a search of these remaining 128 possible phases. In order not to lose synch with the FBCH, in the second phase of the search, it is desirable to switch back and forth between tracking of the FBCH code and attempting acquisition of the pilot code.

The RCS acquisition of short access pilot (SAXPT) algorithm is used by an RCS CDMA modem to acquire the SAXPT pilot signal of an SU. Additional details of this technique are described in U.S. Patent Application entitled "A METHOD OF CONTROLLING INITIAL POWER RAMP-UP IN CDMA SYSTEMS BY USING SHORT CODES" filed on even date herewith and herein incorporated by reference. The algorithm is a fast search algorithm because the SAXPT is a short code sequence of length N, where N=chips/symbol, and ranges from 45 to 195, depending on the system's bandwidth. The search cycles through all possible phases until acquisition is complete.

The RCS acquisition of the long access pilot (LAXPT) algorithm begins immediately after acquisition of SAXPT. The SU's code phase is known within a multiple of a symbol duration, so in the exemplary embodiment of the invention there may be 7 to 66 phases to search within the round trip delay from the RCS. This bound is a result of the SU pilot signal being synchronized to the RCS Global pilot signal.

The re-acquisition algorithm begins when loss of code, lock (LOL) occurs. A Z-search algorithm is used to speed the process on the assumption that the code phase has not drifted far from where it was the last time the system was locked. The RCS uses a maximum width of the Z-search windows bounded by the maximum round trip propagation delay.

The Pre-Track period immediately follows the acquisition or re-acquisition algorithms and immediately precedes the tracking algorithm. Pre-track is a fixed duration period during which the receive data provided by the modem is not considered valid. The Pre-Track period allows other modem algorithms, such as those used by the ISW PLL **1724**, ACQ & Tracking, AMF Weight GEN **1722**, to prepare and adapt to the current channel. The Pre-Track period is two parts. The first part is the delay while the code tracking loop pulls in. The second part is the delay while the AMP tap weight calculations are performed by the AMP Weight Gen **1722** to produce settled weighting coefficients. Also in the second part of the Pre-Track period, the carrier tracking loop is allowed to pull in by the SW PLL **1724**, and the scalar quantile estimates are performed in the Quantile estimator **1723A**.

The Tracking Process is entered after the Pre-Track period ends. This process is actually a repetitive cycle and is the only process phase during which receive data provided by the modem may be considered valid. The following operations are performed during this phase: AMP Tap Weight Update, Carrier Tracking, Code Tracking, Vector Quantile Update, Scalar Quantile Update, Code Lock Check, Derotation and Symbol Summing, and Power Control (forward and reverse)

If LOL is detected, the modem receiver terminates the Track algorithm and automatically enters the reaquisition algorithm. In the SU, a LOL causes the transmitter to be shut down. In the RCS, LOL causes forward power control to be disabled with the transmit power held constant at the level immediately prior to loss of lock. It also causes the return power control information being transmitted to assume a 010101 . . . pattern, causing the SU to hold its transmit power

constant. This can be performed using the signal lock check function which generates the reset signal to the acquisition and tracking circuit **1701**.

Two sets of quantile statistics are maintained, one by Quantile estimator **1723B** and the other by the scalar Quantile Estimator **1723A**. Both are used by the modem controller **1303**. The first set is the "vector" quantile information, so named because it is calculated from the vector of four complex values generated by the AUX AVC receiver **1712**. The second set is the scalar quantile information, which is calculated from the single complex value AUX signal that is output from the AUX Despreader **1707**. The two sets of information represent different sets of noise statistics used to maintain a predetermined Probability of False Alarm (P_{fa}). The vector quantile data is used by the acquisition and reaquisition algorithms implemented by the modem controller **1303** to determine the presence of a received signal in noise, and the scalar quantile information is used by the code lock check algorithm.

For both the vector and scalar cases, quantile information consists of calculated values of lambda0 through lambda2, which are boundary values used to estimate the probability distribution function (p.d.f) of the despread receive signal and determine whether the modem is locked to the PN code. The Aux_Power value used in the following C-subroutine is the magnitude squared of the AUX signal output of the scalar correlator array for the scalar quantiles, and the sum of the magnitudes squared for the vector case. In both cases the quantiles are then calculated using the following C-subroutine:

```
for (n = 0; n < 3; n ++) {
    lambda [n] + = (lambda [n] < Aux_Power) ? CG[n] : GM[n];
    }
```

where CG[n] are positive constants and GM[n] are negative constants (different values are used for scalar and vector quantiles).

During the acquisition phase, the search of the incoming pilot signal with the locally generated pilot code sequence employs a series of sequential tests to determine if the locally generated pilot code has the correct code phase relative to the received signal. The search algorithms use the Sequential Probability Ratio Test (SPRT) to determine whether the received and locally generated code sequences are in phase. The speed of acquisition is increased by parallelism resulting from having a multi-fingered receiver. For example, in the described embodiment of the invention the main Pilot Rake **1711** has a total of 11 fingers representing a total phase period of 11 chip periods. For acquisition 8 separate sequential probability ratio tests (SPRTs) are implemented, with each SPRT observing a 4 chip window. Each window is offset from the previous window by one chip, and in a search sequence any given code phase is covered by 4 windows. If all 8 of the SPRT tests are rejected, then the set of windows is moved by 8 chips. If any of the SPRT's is accepted, then the code phase of the locally generated pilot code sequence is adjusted to attempt to center the accepted SPRT's phase within the Pilot AVC. It is likely that more than one SPRT reaches the acceptance threshold at the same time. A table lookup is used cover all 256 possible combinations of accept/reject and the modem controller uses the information to estimate the correct center code phase within the Pilot Rake **1711**. Each SPRT is implemented as follows (all operations occur at 64 k symbol rate): Denote the fingers' output level values as I_Finger[n] and Q_Finger[n], where n=0 . . . 10 (inclusive, 0 is earliest (most advanced) finger), then the power of each window is:

$$\text{Power Window }[i] = \sum_n (I\_Finger^2[n] + Q\_Finger^2[n])$$

To implement the SPRT's the modem controller then performs for each of the windows the following calculations which are expressed as a pseudo-code subroutine:

```
/* find bin for Power */
tmp = SIGMA[0];
for(k = 0; k < 3; k ++) {
    if (Power > lambda [k]) tmp = SIGMA[k + 1];
}
test_statistic + = tmp; /* update statistic */
if(test_statistic > ACCEPTANCE_THRESHOLD)you've got ACQ;
else if (test_statistic < DISMISSAL_THRESHOLD) {
    forget this code phase;
} else keep trying - get more statistics;
```

where lambda[k] are as defined in the above section on quantile estimation, and SIGMA[k], ACCEPTANCE_THRESHOLD and DISMISSAL_THRESHOLD are predetermined constants. Note that SIGMA[k] is negative for values for low values of k, and positive for right values of k, such that the acceptance and dismissal thresholds can be constants rather than a function of how many symbols worth of data have been accumulated in the statistic.

The modem controller determines which bin delimited by the values of lambda[m] the Power level falls into which allows the modem controller to develop an approximate statistic.

For the present algorithm, the control voltage is formed as $\epsilon = y^T By$, where y is a vector formed from the complex valued output values of the Pilot Vector correlator **1711**, and B is a matrix consisting of the constant values pre-determined to maximize the operating characteristics while minimizing the noise as described previously with reference to the Quadratic Detector.

To understand the operation of the Quadratic Detector, it is useful to consider the following. A spread spectrum (CDMA) signal, s(t) is passed through a multipath channel with an impulse response $h_c(t)$. The baseband spread signal is described by equation (30).

$$s(t) = \sum_i C_i p(t - iT_c) \tag{30}$$

where C_i is a complex spreading code symbol, p(t) is a predefined chip pulse and T_c is the chip time spacing, where $T_c = 1/R_c$ and R_c is the chip rate.

The received baseband signal is represented by equation (31)

$$r(t) = \sum_i C_i q(t - iT_c - \tau) + n(t) \tag{31}$$

where $q(t) = p(t)*h_c(t)$, τ is an unknown delay and n(t) is additive noise. The received signal is processed by a filter, $h_R(t)$, so the waveform, x(t), to be processed is given by equation (32).

$$x(t) = \sum_i C_i f(t - iT_c - \tau) + z(t) \tag{32}$$

where $f(t)=q(t)*h_R(t)$ and $z(t)=n(t)*h_R(t)$.

In the exemplary receiver, samples of the received signal are taken at the chip rate, that is to say, $1/T_c$. These samples, $x(mT_c+\tau')$, are processed by an array of correlators that compute, during the r^{th} correlation period, the quantities given by equation (33)

$$v_k^{(r)} = \sum_{m=rL}^{rL+L-1} x(mT_c + \tau')C^*_{m+k} \tag{33}$$

These quantities are composed of a noise component $w_k^{(r)}$ and a deterministic component $y_k^{(r)}$ given by equation (34).

$$y_k^{(r)}=E[v_{-k}^{(r)}]=Lf(kT_c+\tau'-\tau) \tag{34}$$

In the sequel, the time index r may be suppressed for ease of writing, although it is to be noted that the function f(t) changes slowly with time.

The samples are processed to adjust the sampling phase, τ', in an optimum fashion for further processing by the receiver, such as matched filtering. This adjustment is described below. To simplify the representation of the process, it is helpful to describe it in terms of the function $f(t+\tau)$, where the time-shift, τ, is to be adjusted. It is noted that the function $f(t+\tau)$ is measured in the presence of noise. Thus, it may be problematical to adjust the phase τ' based on measurements of the signal $f(t+\tau)$. To account for the noise, the function $v(t)$: $v(t)=f(t)+m(t)$ is introduced, where the term $m(t)$ represents a noise process. The system processor may be derived based on considerations of the function $v(t)$.

The process is non-coherent and therefore is based on the envelope power function $|v(t+\tau)|^2$. The functional $e(\tau')$ given in equation (35) is helpful for describing the process.

$$e(\tau') = \int_{-\infty}^{0} |v(t+\tau'-\tau)|^2 dt - \int_{0}^{\infty} |v(t+\tau'-\tau)|^2 dt \tag{35}$$

The shift parameter is adjusted for $e(\tau')=0$, which occurs when the energy on the interval $(-\infty,\tau'-\tau]$ equals that on the interval $[\tau'-\tau,\infty)$. The error characteristic is monotonic and therefore has a single zero crossing point. This is the desirable quality of the functional. A disadvantage of the functional is that it is ill-defined because the integrals are unbounded when noise is present. Nevertheless, the functional $e(\tau')$ may be cast in the form given by equation (36).

$$e(\tau') = \int_{-\infty}^{\infty} w(t)|v(t+\tau'-\tau)|^2 dt \tag{36}$$

where the characteristic function $w(t)$ is equal to $\mathrm{sgn}(t)$, the signum function.

To optimize the characteristic function $w(t)$, it is helpful to define a figure of merit, F, as set forth in equation (37).

$$F = \frac{[e(\tau_0'+T_A) - e(\tau_0'-T_A)]^2}{\mathrm{VAR}\{e(\tau_0')\}} \tag{37}$$

The numerator of F is the numerical slope of the mean error characteristic on the interval $[-T_A,T_A]$ surrounding the tracked value, τ_0'. The statistical mean is taken with respect to the noise as well as the random channel, $h_c(t)$. It is desirable to specify a statistical characteristic of the channel in order to perform this statistical average. For example, the channel may be modeled as a Wide Sense Stationary Uncorrelated Scattering (WSSUS) channel with impulse response $h_c(t)$ and a white noise process $U(t)$ that has an intensity function $g(t)$ as shown in equation (38).

$$h_c(t)=\sqrt{g(t)}U(t) \tag{38}$$

The variance of $e(\tau)$ is computed as the mean square value of the fluctuation

$$e'(\tau)=e(\tau)-\langle e(\tau)\rangle \tag{39}$$

where $\langle e(\tau)\rangle$ is the average of $e(\tau)$ with respect to the noise.

Optimization of the figure of merit F with respect to the function $w(t)$ may be carried out using well-known Variational methods of optimization.

Once the optimal $w(t)$ is determined, the resulting processor may be approximated accurately by a quadratic sample processor which is derived as follows.

By the sampling theorem, the signal $v(t)$, bandlimited to a bandwidth W may be expressed in terms of its samples as shown in equation (40).

$$v(t) = \sum v(k/W)\mathrm{sinc}[(Wt-k)\pi] \tag{40}$$

substituting this expansion into equation (z+6) results in an infinite quadratic form in the samples $v(k/W+\tau'-\tau)$. Making the assumption that the signal bandwidth equals the chip rate allows the use of a sampling scheme that is clocked by the chip clock signal to be used to obtain the samples. These samples, V_k are represented by equation (41).

$$v_k=v(kT_c+\tau'-\tau) \tag{41}$$

This assumption leads to a simplification of the implementation. It is valid if the aliasing error is small.

In practice, the quadratic form that is derived is truncated. An example normalized B matrix is given below in Table 12. For this example, an exponential delay spread profile $g(t)=\exp(-t/\tau)$ is assumed with τ equal to one chip. An aperture parameter T_A equal to one and one-half chips has also been assumed. The underlying chip pulse has a raised cosine spectrum with a 20% excess bandwidth.

TABLE 12

Example B matrix

0	0	0	0	0	0	0	0	0	0	0
0	0	−0.1	0	0	0	0	0	0	0	0
0	−0.1	0.22	0.19	−0.19	0	0	0	0	0	0
0	0	0.19	1	0.45	−0.2	0	0	0	0	0
0	0	−0.19	0.45	0.99	0.23	0	0	0	0	0
0	0	0	−0.2	0.23	0	−0.18	0.17	0	0	0
0	0	0	0	0	−0.18	−0.87	−0.42	0.18	0	0
0	0	0	0	0	0.17	−0.42	−0.92	−0.16	0	0
0	0	0	0	0	0	0.18	−0.16	−0.31	0	0
0	0	0	0	0	0	0	0	0	−0.13	0
0	0	0	0	0	0	0	0	0	0	0

Code tracking is implemented via a loop phase detector that is implemented as follows. The vector y is defined as a column vector which represents the 11 complex output level values of the Pilot AVC 1711, and B denotes an 11×11 symmetric real valued coefficient matrix with pre-determined values to optimize performance with the non-coherent Pilot AVC output values y. The output signal ϵ of the phase detector is given by equation (42):

$$\epsilon = y^T B y \tag{42}$$

The following calculations are then performed to implement a proportional plus integral loop filter and the VCO:

$$x[n]=x[n-1]+\beta\epsilon$$

$$z[n]=z[n-1]+x[n]+\alpha\epsilon$$

for β and α which are constants chosen from modeling the system to optimize system performance for the particular transmission channel and application, and where x[n] is the loop filter's integrator output value and z[n] is the VCO output value. The code phase adjustments are made by the modem controller the following C-subroutine:

```
if (z > zmx) {
    delay phase 1/16 chip;
    z -= zmax;
} else if (z < -zmax) {
    advance phase 1/16 chip;
    z += zmax;
}
```

A different delay phase could be used in the above pseudo-code consistant with the present invention.

The AMF Tap-Weight Update Algorithm of the AMF Weight Gen 1722 occurs periodically to de-rotate and scale the phase of each finger value of the Pilot Rake 1711 by performing, a complex multiplication of the Pilot AVC finger value with the complex conjugate of the current output value of the carrier tracking loop and applying the product to a low pass filter and form the complex conjugate of the filter values to produce AMF tap-weight values, which are periodically written into the AMF filters of the CDMA modem.

The lock check algorithm, shown in FIG. 17, is implemented by the modem controller 1303 performing SPRT operations on the output signal of the scalar correlator array. The SPRT technique is the same as that for the acquisition algorithms, except that the acceptance and rejection thresholds are changed to increase the probability of detection of lock.

Carrier tracking is accomplished via a second order loop that operates on the pilot output values of the scalar correlated array. The phase detector output is the hard limited version of the quadrature component of the product of the (complex valued) pilot output signal of the scalar correlated array and the VCO output signal. The loop filter is a proportional plus integral design. The VCO is a pure summation, accumulated phase error ϕ, which is converted to the complex phasor $\cos\phi + j\sin\phi$ using a look-up table in memory.

The previous description of acquisition and tracking algorithm focuses on a non-coherent method because the acquisition and tracking algorithm described requires non-coherent acquisition following by non-coherent tracking because during acquisition a coherent reference is not available until the AMF, Pilot AVC, Aux AVC, and DPLL are in an equilibrium state. However, it is known in the art that coherent tracking and combining is always optimal because in non-coherent tracking and combining the output phase information of each Pilot AVC finger is lost. Consequently, another embodiment of the invention employs a two step acquisition and tracking system, in which the previously described non-coherent acquisition and tracking algorithm is

implemented first, and then the algorithm switches to a coherent tracking method. The coherent combining and tracking method is similar to that described previously, except that the error signal tracked is of the form:

$$\epsilon = y^T A y \tag{43}$$

where y is defined as a column vector which represents the 11 complex output level values of the Pilot AVC 1711, and A denotes an 11×11 symmetric real valued coefficient matrix with pre-determined values to optimize performance with the coherent Pilot AVC outputs y. An exemplary A matrix is shown below.

$$A = \begin{matrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1
\end{matrix} \tag{44}$$

Referring to FIG. 9, the Video Distribution Controller Board (VDC) 940 of the RCS is connected to each MIU 931, 932, 933 and the RF Transmitters/Receivers 950. The VDC 940 is shown in FIG. 21. The Data Combiner Circuitry (DCC) 2150 includes a Data Demultiplexer 2101, Data Summer 2102, FIR Filters 2103, 2104, and a Driver 2111. The DCC 2150 1) receives the weighted CDMA modem I and Q data signal MDAT from each of the MIUs, 931, 932, 933, 2) sums the I and Q data with the digital bearer channel data from each MIU 931, 932, 933, 3) and sums the result with the broadcast data message signal BCAST and the Global Pilot spreading code GPILOT provided by the master MIU modem 1210, 4) band shapes the summed signals for transmission, and 5) produces analog data signal for transmission to the RF Transmitter/Receiver.

FIR Filters 2103, 2104 are used to modify the MIU CDMA Transmit I and Q Modem Data before transmission. The WAC transfers FIR Filter Coefficient data through the Serial Port link 912 through the VDC Controller 2120 and to the FIR filters 2103, 2104. Each FIR Filter 2103, 2104 is Configured separately. The FIR Filters 2103, 2104 employ Up-Sampling to operate at twice the chip rate so zero data values are sent after every MIU CDMA Transmit Modem DATI and DATQ value to produce FTXI and FTXQ

The VDC 940 distributes the AGC signal AGCDATA from the AGC 1750 of the MIUs 931, 932, 933 to the RF Transmitter/Receiver 950 through the Distribution interface (DI) 2110. The VDC DI 2110 receives data RXI and RXQ from the RF Transmitter/Receiver and distributes the signal as VDATAI and VDATAQ to MIUs 931, 932, 933.

Referring to FIG. 21, the VDC 940 also includes a VDC controller 2120 which monitors status and fault information signals MIUSTAT from MIUs and connects to the serial link 912 and HSBS 970 to communicate with WAC 920 shown in FIG. 9. The VDC controller 2120 includes a microprocessor, such as an Intel 8032 Microcontroller, an oscillator (not shown) providing timing signals, and memory (not shown). The VDC controller memory includes a Flash Prom (not shown) to contain the controller program code for the 8032 Microprocessor, and an SRAM (not shown) to

contain the temporary data written to and read from memory by the microprocessor.

Referring to FIG. 9, the present invention includes a RF Transmitter/Receiver 950 and power amplifier section 960. Referring to FIG. 22, the RF Transmitter/Receiver 950 is divided into three sections: the transmitter module 2201, the receiver module 2202, and the Frequency Synthesizer 2203. Frequency Synthesizer 2203 produces a transmit carrier frequency TFREQ and a receive carrier frequency RFREQ in response to a Frequency control signal FREQCTRL received from the WAC 920 on the serial link 912. In the transmitter module 2201, the input analog I and Q data signals TXI and TXQ from the VDC are applied to the Quadrature modulator 2220, which also receives a transmit carrier frequency signal TFREQ from the Frequency Synthesizer 2203 to produce a quadrature modulated transmit carrier signal TX. The analog transmit carrier modulated signal, an upconverted RF signal, TX is then applied to the Transmit Power Amplifier 2252 of the Power Amplifier 960. The amplified transmit carrier signal is then passed through the High Power Passive Components (HPPC) 2253 to the Antenna 2250, which transmits the upconverted RF signal to the communication channel as a CDMA RF signal. In one embodiment of the invention, the Transmit Power Amplifier 2252 comprises eight amplifiers of approximately 60 watts peak-to-peak each.

The HPPC 2253 comprises a lightning protector, an output filter, a 10 dB directional coupler, an isolator, and a high power termination attached to the isolator.

A receive CDMA RF signal is received at the antenna 2250 from the RF channel and passed through the HPPC 2253 to the Receive Power Amplifier 2251. The receive power amplifier 2251 includes, for example, a 30 watt power transistor driven by a 5 watt transistor. The RF receive module 2202 has quadrature modulated receive carrier signal RX from the receive power amplifier. The receive module 2202 includes a Quadrature demodulator 2210 which takes the receive carrier modulated signal RX and the receive carrier frequency signal RFREQ from the Frequency Synthesizer 2203, synchronously demodulates the carrier, and provides analog I and Q channels. These channels are filtered to produce the signals RXI and RXQ, which are transferred to the VDC 940.

The Subscriber Unit

FIG. 23 shows the Subscriber Unit (SU) of one embodiment of the present invention. As shown, the SU includes an RF section 2301 including a RF modulator 2302, RF demodulator 2303, and splitter/isolator 2304 which receive Global and Assigned logical channels including traffic and control messages and Global Pilot signals in the Forward link CDMA RF channel signal, and transmit Assigned Channels and Reverse Pilot signals in the Reverse Link CDMA RF channel. The Forward and Reverse links are received and transmitted respectively through antenna 2305. The RF section employs, in one exemplary embodiment, a conventional dual conversion superheterodyne receiver having a synchronous demodulator responsive to the signal ROSC. Selectivity of such a receiver is provided by a 70 MHz transversal SAW filter (not shown). The RF modulator includes a synchronous modulator (not shown) responsive to the carrier signal TOSC to produce a quadrature modulated carrier signal. This signal is stepped up in frequency by an offset mixing circuit (not shown).

The SU further includes a Subscriber Line Interface 2310, including the functionality of a control (CC) generator, a Data Interface 2320, an ADPCM encoder 2321, an ADPCM

decoder 2322, an SU controller 2330, an SU clock signal generator 2331, memory 2332, and a CDMA modem 2340, which is essentially the same as the CDMA modem 1210 described above wih reference to FIG. 13. It is noted that data interface 2320, ADPCM Encoder 2321 and ADPCM Decoder 2322 are typically provided as a standard ADPCM Encoder/Decoder chip.

The Forward Link CDMA RF Channel signal is applied to the RF demodulator 2303 to produce the Forward link CDMA signal. The Forward Link CDMA signal is provided to the CDMA modem 2340, which acquires synchronization with the Global pilot signal, produces global pilot synchronization signal to the Clock 2331, to generate the system timing signals, and despreads the plurality of logical channels. The CDMA modem 2340 also acquires the traffic messages RMESS and control messages RCTRL and provides the traffic message signals RMESS to the Data Interface 2320 and receive control message signals RCTRL to the SU Controller 2330.

The receive control message signals RCTRL include a subscriber identification signal, a coding signal, and bearer modification signals. The RCTRL may also include control and other telecommunication signaling information. The receive control message signal RCTRL is applied to the SU controller 2330, which verifies that the call is for the SU from the Subscriber identification value derived from RCTRL. The SU controller 2330 determines the type of user information contained in the traffic message signal from the coding signal and bearer rate modification signal. If the coding signal indicates the traffic message is ADPCM coded, the traffic message RVMESS is sent to the ADPCM decoder 2322 by sending a select message to the Data Interface 2320. The SU controller 2330 outputs an ADPCM coding signal and bearer rate signal derived from the coding signal to the ADPCM decoder 2322. The traffic message signal RVMESS is the input signal to the ADPCM decoder 2322, where the traffic message signal is converted to a digital information signal RINF in response to the values of the input ADPCM coding signal.

If the SU controller 2330 determines the type of user information contained in the traffic message signal from the coding signal is not ADPCM coded, then RDMESS passes through the ADPCM encoder transparently. The traffic message RDMESS is transferred from the Data Interface 2320 directly to the Interface Controller (IC) 2312 of the subscriber line interface 2310.

The digital information signal RINF or RDMESS is applied to the subscriber line interface 2310, including a interface controller (IC) 2312 and Line Interface (LI) 2313. For the exemplary embodiment the IC is an Extended PCM Interface Controller (EPIC) and the LI is a Subscriber Line Interface Circuit (SLIC) for POTS which corresponds to RINF type signals, and a ISDN Interface for ISDN which corresponds to RDMESS type signals. The EPIC and SLIC circuits are well known in the art. The subscriber line interface 2310 converts the digital information signal RINF or RDMESS to the user defined format. The user defined format is provided to the IC 2312 from the SU Controller 2330. The LI 2310 includes circuits for performing such functions as A-law or μ-law conversion, generating dial tone and, and generating or interpreting signaling bits. The line interface also produces the user information signal to the SU User 2350 as defined by the subscriber line interface, for example POTS voice, voiceband data or ISDN data service.

For a Reverse Link CDMA RF Channel, a user information signal is applied to the LI 2313 of the subscriber line

interface **2310**, which outputs a service type signal and an information type signal to the SU controller. The IC **2312** of the subscriber line interface **2310** produces a digital information signal TINF which is the input signal to the ADPCM encoder **2321** if the user information signal is to be ADPCM encoded, such as for POTS service. For data or other non-ADPCM encoded user information, the IC **2312** passes the data message TDMESS directly to the Data Interface **2320**. The Call control module (CC), including in the subscriber line interface **2310**, derives call control information from the User information signal, and passes the call control information CCINF to the SU controller **2330**. The ADPCM encoder **2321** also receives coding signal and bearer modification signals from the SU controller **2330** and converts the input digital information signal into the output message traffic signal TVMESS in response to the coding and bearer modification signals The SU controller **2330** also outputs the reverse control signal which includes the coding signal call control information, and bearer channel modification signal, to the CDMA modem. The output message signal TVMESS is applied to the Data Interface **2320**. The Data Interface **2320** sends the user information to the CDMA modem **2340** as transmit message signal TMESS. The CDMA modem **2340** spreads the output message and reverse control channels TCTRL received from the SU controller **2330**, and produces the reverse link CDMA Signal. The Reverse Link CDMA signal is provided to the RF transmit section **2301** and modulated by the RF modulator **2302** to produce the output Reverse Link CDMA RF channel signal transmitted from antenna **2305**.

Call Connection and Establishment Procedure

The process of bearer channel establishment consists of two procedures: the call connection process for a call connection incoming from a remote call processing unit such as an RDU (Incoming Call Connection), and the call connection process for a call outgoing from the SU (Outgoing Call Connection). Before any bearer channel can be established between an RCS and a SU, the SU must register its presence in the network with the remote call processor such as the RDU. When the off-hook signal is detected by the SU, the SU not only begins to establish a bearer channel; but also initiates the procedure for an RCS to obtain a terrestrial link between the RCS and the remote processor. As incorporated herein by reference, the process of establishing the RCS and RDU connection is detailed in the DECT V5.1 standard.

For the Incoming Call Connection procedure shown in FIG. **24**, first **2401**, the WAC **920** (shown in FIG. **9**) receives, via one of the MUXs **905**, **906** and **907**, an incoming call request from a remote call processing unit. This request identifies the target SU and that a call connection to the SU is desired. The WAC periodically outputs the SBCH channel with paging indicators for each SU and periodically outputs the FBCH traffic lights for each access channel. In response to the incoming call request, the WAC, at step **2420**, first checks to see if the identified SU is already active with another call. If so, the WAC returns a busy signal for the SU to the remote processing unit through the MUX, otherwise the paging indicator for the channel is set

Next, at step **2402**, the WAC checks the status of the RCS modems and, at step **2421**, determines whether there is an available modem for the call. If a modem is available, the traffic lights on the FBCH indicate that one or more AXCH channels are available. If no channel is available after a certain period of time, then the WAC returns a busy signal for the SU to the remote processing unit through the MUX.

If an RCS modem is available and the SU is not active (in Sleep mode), the WAC sets the paging indicator for the identified SU on the SBCH to indicate an incoming call request. Meanwhile, the access channel modems continuously search for the Short Access Pilot signal (SAXPT) of the SU.

At step **2403**, an SU in Sleep mode periodically enters awake mode. In awake mode, the SU modem synchronizes to the Downlink Pilot signal, waits for the SU modem AMF filters and phase locked loop to settle, and reads the paging indicator in the slot assigned to it on the SBCH to determine if there is a call for the SU **2422**. If no paging indicator is set, the SU halts the SU modem and returns to sleep mode. If a paging indicator is set for an incoming call connection, the SU modem checks the service type and traffic lights on FBCH for an available AXCH.

Next, at step **2404**, the SU modem selects an available AXCH and starts a fast transmit power ramp-up on the corresponding SAXPT. For a period the SU modem continues fast power ramp-up on SAXPT and the access modems continue to search for the SAXPT.

At step **2405**, the RCS modem acquires the SAXPT of the SU and begins to search for the SU LAXPT. When the SAXPT is acquired, the modem informs the WAC controller, and the WAC controller sets the traffic lights corresponding to the modem to "red" to indicate the modem is now busy. The traffic lights are periodically output while continuing to attempt acquisition of the LAXPT.

The SU modem monitors, at step **2406**, the FBCH AXCH traffic light. When the AXCH traffic light is set to red, the SU assumes the RCS modem has acquired the SAXPT and begins transmitting LAXPT. The SU modem continues to ramp-up power of the LAXPT at a slower rate until Sync-Ind messages are received on the corresponding CTCH. If the SU is mistaken because the traffic light was actually set in response to another SU acquiring the AXCH, the SU modem times out because no Sync-Ind messages are received. The SU randomly waits a period of time, picks a new AXCH channel, and steps **2404** and **2405** are repeated until the SU modem receives Sync-Ind messages. Details of the power ramp up method used in the exemplary embodiment of this invention may be found in the U.S. patent application entitled METHOD OF CONTROLLING INITIAL POWER RAMP-UP IN CDMA SYSTEMS BY USING SHORT CODES filed on even date herewith, which is hereby incorporated by reference.

Next, at step **2407**, the RCS modem acquires the LAXPT of the SU and begins sending Sync-Ind messages on the corresponding CTCH. The modem waits 10 msec for the Pilot and AUX Vector correlator filters and Phase locked loop to settle, but continues to send Synch-Ind messages on the CTCH. The modem then begins looking for a request message for access to a bearer channel (MAC_ACC_REQ), from the SU modem.

The SU modem, at step **2408**, receives the Sync-Ind message and freezes the LAXPT transmit power level. The SU modem then begins sending repeated request messages for access to a bearer traffic channel (MAC_ACC_REQ) at fixed power levels, and listens for a request confirmation message (MAC_BEARER_CFM) from the RCS modem.

Next, at step **2409**, the RCS modem receives a MAC_ACC_REQ message; the modem then starts measuring the AXCH power level, and starts the APC channel. The RCS modem then sends the MAC_BEARER_CPM message to the SU and begins listening for the acknowledgment MAC_BEARER_CFM_ACK of the MAC_BEARER_CFM message.

At step **2410**, the SU modem receives the MAC_BEARER_CFM message and begins obeying the APC power control messages. The SU stops sending the MAC_ACC_REQ message and sends the RCS modem the MAC_BEARER_CFM_ACK message. The SU begins sending the null data on the AXCH. The SU waits 10 msec for the uplink transmit power level to settle.

The RCS modem, at step **2411**, receives the MAC_BEARER_CFM_ACK message and stops sending the MAC_BEARER_CFM messages. APC power measurements continue.

Next, at step **2412**, both the SU and the RCS modems have synchronized the sub-epochs, obey APC messages, measure receive power levels, and compute and send APC messages. The SU waits 10 msec for downlink power level to settle.

Finally, at step **2413**, Bearer channel is established and initialized between the SU and RCS modems. The WAC receives the bearer establishment signal from the RCS modem, re-allocates the AXCH channel and sets the corresponding traffic light to green.

For the Outgoing Call Connection shown in FIG. **25**, the SU is placed in active mode by the off-hook signal at the user interface at step **2501**.

Next, at step **2502**, the RCS indicates available AXCH channels by setting the respective traffic lights.

At step **2503**, the SU synchronizes to the Downlink Pilot, waits for the SU modem Vector correlator filters and phase lock loop to settle, and the SU checks service type and traffic lights for an available AXCH.

Steps **2504** through **2513** are identical to the procedure steps **2404** through **2413** for the Incoming Call Connection procedure of FIG. **24**, and so are not explained in detail.

In the previous procedures for Incoming Call Connection and Outgoing Call Connection, the power Ramping-Up process consists of the following events. The SU starts from very low transmit power and increases its power level while transmitting the short code SAXPT; once the RCS modem detects the short code it turns off the traffic light. Upon detecting the changed traffic light, the SU continues ramping-up at a slower rate this time sending the LAXPT. Once the RCS modem acquires the LAXPT and sends a message on CTCH to indicate this, the SU keeps its transmit (TX) power constant and sends the MAC-Access-Request message. This message is answered with a MAC_BEARER_CFM message on the CTCH. Once the SU receives the MAC_BEAER_CFM message it switches to the traffic channel (TRCH) which is the dial tone for POTS.

When the SU captures a specific user channel AXCH, the RCS assigns a code seed for the SU through the CTCH. The code seed is used by the spreading code generator in the SU modem to produce the assigned code for the reverse pilot of the subscriber, and the spreading codes for associated channels for traffic, call control, and signaling. The SU reverse pilot spreading code sequence is synchronized in phase to the RCS system Global Pilot spreading code sequence, and the traffic, call control, and signaling spreading codes are synchronized in phase to the SU reverse pilot spreading code sequence.

If the Subscriber unit is successful in capturing a specific user channel, the RCS establishes a terrestrial link with the remote processing unit to correspond to the specific user channel. For the DECT V5.1 standard, once the complete link from the RDU to the LE is established using the V5.1 ESTABLISHMENT message, a corresponding V5.1 ESTABLISHMENT ACK message is returned from the LE to the RDU, and the Subscriber Unit is sent a CONNECT message indicating that the transmission link is complete.

Support of Special Service Types

The system of the present invention includes a bearer channel modification feature which allows the transmission rate of the user information to be switched from a lower rate to a maximum of 64 kb/s. The Bearer Channel Modification (BCM) method is used to change a 32 kb/s ADPCM channel to a 64 kb/s PCM channel to support high speed data and fax communications through the spread-spectrum communication system of the present invention. Additional details of this technique are described in U.S. Patent Application entitled "CDMA COMMUNICATION SYSTEM WHICH SELECTIVELY SUPPRESSES DATA TRANSMISSIONING DURING ESTABLISHMENT OF A COMMUNICATION CHANNEL" filed on even date herewith and incorporated herein by reference.

First, a bearer channel on the RF interface is established between the RCS and SU, and a corresponding link exists between the RCS terrestrial interface and the remote processing unit such as an RDU. The digital transmission rate of the link between the RCS and remote processing unit normally corresponds to a data encoded rate, which may be, for example, ADPCM at 32 kb/s. The WAC controller of the RCS monitors the encoded digital data information of the link received by the Line Interface of the MUX. If the WAC controller detects the presence of the 2100 Hz tone in the digital data, the WAC instructs the SU through the assigned logical control channel and causes a second, 64 kb/s duplex link to be established between the RCS modem and the SU. In addition, the WAC controller instructs the remote processing unit to establish a second 64 kb/s duplex link between the remote processing unit and the RCS. Consequently, for a brief period, the remote processing unit and the SU exchange the same data over both the 32 kb/s and the 64 kb/s links through the RCS. Once the second link is established, the remote processing unit causes the WAC controller to switch transmission only to the 64 kb/s link, and the WAC controller instructs the RCS modem and the SU to terminate and tear down the 32 kb/s link. Concurrently, the 32 kb/s terrestrial link is also terminated and torn down.

Another embodiment of the BCM method incorporates a negotiation between the external remote processing unit, such as the RDU, and the RCS to allow for redundant channels on the terrestrial interface, while only using one bearer channel on the RF interface. The method described is a synchronous switchover from the 32 kb/s link to the 64 kb/s link over the air link which takes advantage of the fact that the spreading code sequence timing is synchronized between the RCS modem and SU. When the WAC controller detects the presence of the 2100 Hz tone in the digital data, the WAC controller instructs the remote processing unit to establish a second 64 kb/s duplex link between the remote processing unit and the RCS. The remote processing unit then sends 32 kb/s encoded data and 64 kb/s data concurrently to the RCS. Once the remote processing unit has established the 64 kb/s link, the RCS is informed and the 32 kb/s link is terminated and torn down. The RCS also informs the SU that the 32 kb/s link is being torn down and to switch processing to receive unencoded 64 kb/s data on the channel. The SU and RCS exchange control messages over the bearer control channel of the assigned channel group to identify and determine the particular subepoch of the bearer channel spreading code sequence within which the RCS will begin

transmitting 64 kbit/sec data to the SU. Once the subepoch is identified, the switch occurs synchronously at the identified subepoch boundary. This synchronous switchover method is more economical of bandwidth since the system does not need to maintain capacity for a 64 kb/s link in order to support a switchover.

The previously described embodiments of the BCM feature, the RCS will tear down the 32 kb/s link first, but one skilled in the art would know that the RCS could tear down the 32 kb/s link after the bearer channel has switched to the 64 kb/s link.

As another special service type, the system of the present invention includes a method for conserving capacity over the RF interface for ISDN types of traffic. This conservation occurs while a known idle bit pattern is transmitted in the ISDN D-channel when no data information is being transmitted. The CDMA system of the present invention includes a method to prevent transmission of redundant information carried on the D-channel of ISDN networks for signals transmitted through a wireless communication link. The advantage of such method is that it reduces the amount of information transmitted and consequently the transmit power and channel capacity used by that information. The method is described as it is used in the RCS. In the first step, the controller, such as the WAC of the RCS or the SU controller of the SU, monitors the output D-channel from the subscriber line interface for a pre-determined channel idle pattern. A delay is included between the output of the line interface and the CDMA modem. Once the idle pattern is detected, the controller inhibits the transmission of the spread message channel through a message included in the control signal to the CDMA modem. The controller continues to monitor the output D-channel of the line interface until the presence of data information is detected. When data information is detected, the spread message channel is activated. Because the message channel is synchronized to the associated pilot which is not inhibited, the corresponding CDMA modem of the other end of the communication link does not have to reacquire synchronization to the message channel.

Drop Out Recovery

The RCS and SU each monitor the CDMA bearer channel signal to evaluate the quality of the CDMA bearer channel connection. Link quality is evaluated using the sequential probability ratio test (SPRT) employing adaptive quantile estimation. The SPRT process uses measurements of the received signal power; and if the SPRT process detects that the local spreading code generator has lost synchronization with the received signal spreading code or if it detects the absence or low level of a received signal, the SPRT declares loss of lock (LOL).

When the LOL condition is declared, the receiver modem of each RCS and SU begins a Z-search of the input signal with the local spreading code generator. Z-search is well known in the art of CDMA spreading code acquisition and detection and is described in *Digital Communications and Spread Spectrum Systems,* by Robert E. Ziemer and Roger L. Peterson, at pages 492–94 which is incorporated herein by reference. The Z-search algorithm of the present invention tests groups of eight spreading code phases ahead and behind the last known phase in larger and larger spreading code phase increments.

During the LOL condition detected by the RCS, the RCS continues to transmit to the SU on the Assigned Channels, and continues to transmit power control signals to the SU to maintain SU transmit power level. The method of transmitting power control signals is described below. Successful reacquisition desirably takes place within a specified period of time. If reacquisition is successful, the call connection continues, otherwise the RCS tears down the call connection by deactivating and deallocating the RCS modem assigned by the WAC, and transmits a call termination signal to a remote call processor, such as the RDU, as described previously.

When the LOL condition is detected by the SU, the SU stops transmission to the RCS on the Assigned Channels which forces the RCS into a LOL condition, and starts the reacquisition algorithm. If reacquisition is successful, the call connection continues, and if not successful, the RCS tears down the call connection by deactivating and deallocating the SU modem as described previously.

Power Control

General

The power control feature of the present invention is used to minimize the amount of transmit power used by an RCS and the SUs of the system, and the power control subfeature that updates transmit power during bearer channel connection is defined as automatic power control (APC). APC data is transferred from the RCS to an SU on the forward APC channel and from an SU to the RCS on the reverse APC channel. When there is no active data link between the two, the maintenance power control (MPC) subfeature updates the SU transmit power.

Transmit power levels of forward and reverse assigned channels and reverse global channels are controlled by the APC algorithm to maintain sufficient signal power to interference noise power ratio (SIR) on those channels, and to stabilize and minimize system output power. The present invention uses a closed loop power control mechanism in which a receiver decides that the transmitter should incrementally raise or lower its transmit power. This decision is conveyed back to the respective transmitter via the power control signal on the APC channel. The receiver makes the decision to increase or decrease the transmitter's power based on two error signals. One error signal is an indication of the difference between the measured and desired despread signal powers, and the other error signal is an indication of the average received total power.

As used in the described embodiment of the invention, the term near-end power control is used to refer to adjusting the transmitter's output power in accordance with the APC signal received on the APC channel from the other end. This means the reverse power control for the SU and forward power control for the RCS; and the term far-end APC is used to refer to forward power control for the SU and reverse power control for the RCS (adjusting the opposite end's transmit power).

In order to conserve power, the SU modem terminates transmission and powers-down while waiting for a call, defined as the sleep phase. Sleep phase is terminated by an awaken signal from the SU controller. The SU modem acquisition circuit automatically enters the reacquisition phase, and begins the process of acquiring the downlink pilot, as described previously.

Closed Loop Power Control Algorithms

The near-end power control consists of two steps: first, the initial transmit power is set; and second, the transmit power is continually adjusted according to information received from the far-end using APC.

For the SU, initial transmit power is set to a minimum value and then ramped up, for example, at a rate of 1 dB/ms until either a ramp-up timer expires (not shown) or the RCS changes the corresponding traffic light value on the FBCH to "red" indicating that the RCS has locked to the SU's short pilot SAXPT. Expiration of the timer causes the SAXPT transmission to be shut down, unless the traffic light value is set to red first, in which case the SU continues to ramp-up transmit power but at a much lower rate than before the "red" signal was detected.

For the RCS, initial transmit power is set at a fixed value, corresponding to the minimum value necessary for reliable operation as determined experimentally for the service type and the current number of system users. Global channels, such as Global Pilot or, FBCH, are always transmitted at the fixed initial power, whereas traffic channels are switched to APC.

The APC bits are transmitted as one bit up or down signals on the APC channel. In the described embodiment, the 64 kb/s APC data stream is not encoded or interleaved.

Far-end power control consists of the near-end transmitting power control information for the far-end to use in adjusting its transmit power.

The APC algorithm causes the RCS or the SU to transmit +1 if the following inequality holds, otherwise −1.

$$\alpha_1 e_1 - \alpha_2 e_2 > 0 \quad (45)$$

Here, the error signal e_1 is calculated as

$$e_1 = P_d - (1 + SNR_{REQ}) P_N \quad (46)$$

where P_d is the despread signal plus noise power, P_N is the despread noise power, and SNR_{REQ} is the desired despread signal to noise ratio for the particular service type; and

$$e_2 = P_r - P_o \quad (47)$$

where Pr is a measure of the received power and Po is the automatic gain control (AGC) circuit set point. The weights α_1 and α_2 in equation (33) are chosen for each service type and APC update rate.

Maintenance Power Control

During the sleep phase of the SU, the interference noise power of the CDMA RF channel may change. The present invention includes a maintenance power control feature (MPC) which periodically adjusts the SU's initial transmit power with respect to the interference noise power of the CDMA channel. The MPC is the process whereby the transmit power level of an SU is maintained within close proximity of the minimum level for the RCS to detect the SU's signal. The MPC process compensates for low frequency changes in the required SU transmit power.

The maintenance control feature uses two global channels: one is called the status channel (STCH) on reverse link, and the other is called the check-up channel (CUCH) on forward link. The signals transmitted on these channels carry no data and they are generated the same way the short codes used in initial power ramp-up are generated. The STCH and CUCH codes are generated from a "reserved" branch of the global code generator.

The MPC process is as follows. At random intervals, the SU sends a symbol length spreading code periodically for 3 ms on the status channel (STCH). If the RCS detects the sequence, it replies by sending a symbol length code sequence within the next 3 ms on the check-up channel (CUCH). When the SU detects the response from the RCS, it reduces its transmit power by a particular step size. If the SU does not see any response from the RCS within that 3 ms period, it increases its transmit power by the step size. Using this method, the RCS response is transmitted at a power level that is enough to maintain a 0.99 detection probability at all SU's.

The rate of change of traffic load and the number of active users is related to the total interference noise power of the CDMA channel. The update rate and step size of the maintenance power update signal for the present invention is determined by using queuing theory methods well known in the art of communication theory, such as outlined in "*Fundamentals of Digital Switching*" (Plenum-New York) edited by McDonald and incorporated herein by reference. By modeling the call origination process as an exponential random variable with mean 6.0 mins, numerical computation shows the maintenance power level of a SU should be updated once every 10 seconds or less to be able to follow the changes in interference level using 0.5 dB step size. Modeling the call origination process as a Poisson random variable with exponential interarrival times, arrival rate of 2×10^{-4} per second per user, service rate of $\frac{1}{360}$ per second, and the total subscriber population is 600 in the RCS service area also yields by numerical computation that an update rate of once every 10 seconds is sufficient when 0.5 dB step size is used.

Maintenance power adjustment is performed periodically by the SU which changes from sleep phase to awake phase and performs the MPC process. Consequently, the process for the MPC feature is shown in FIG. 26 and is as follows: First, at step **2601**, signals are exchanged between the SU and the RCS maintaining a transmit power level that is close to the required level for detection: the SU periodically sends a symbol length spreading code in the STCH, and the RCS periodically sends a symbol length spreading code in the CUCH as response.

Next, at step **2602**, if the SU receives a response within 3 ms after the STCH message it sent, it decreases its transmit power by a particular step size at step **2603**; but if the SU does not receive a response within 3 ms after the STCH message, it increases its transmit power by the same step size at step **2604**.

The SU waits, at step **2605**, for a period of time before sending another STCH message, this time period is determined by a random process which averages 10 seconds.

Thus, the transmit power of the STCH messages from the SU is adjusted based on the RCS response periodically, and the transmit power of the CUCH messages from the RCS is fixed.

Mapping of Power Control Signal to Logical Channels For APC

Power control signals are mapped to specified Logical Channels for to controlling transmit power levels of forward and reverse assigned channels. Reverse global channels are also controlled by the APC algorithm to maintain sufficient signal power to interference noise ratio (SIR) on those reverse channels, and to stabilize and minimize system output power. The present invention uses a closed loop power control method in which a receiver periodically decides to incrementally raise or lower the output power of the transmitter at the other end. The method also conveys that decision back to the respective transmitter.

TABLE 13

APC Signal Channel Assignments

Link Channels and Signals	Call/ Connection Status	Power Control Method: Initial Value	Power Control Method: Continuous
Reverse link AXCH AXPT	Being Established	as determined by power ramping	APC bits in forward APC channel
Reverse link APC, OW, TRCH, pilot signal	In-Progress	level established during call set-up	APC bits in forward APC channel
Forward link APC, OW, TRCH	In-Progress	fixed value	APC bits in reverse APC channel

Forward and reverse links are independently controlled. For a call/connection in process, forward link (TRCHs APC, and OW) power is controlled by the APC bits transmitted on the reverse APC channel. During the call/connection establishment process, reverse link (AXCH) power is also controlled by the APC bits transmitted on the forward APC channel. Table 13 summarizes the specific power control methods for the controlled channels.

The required SIRs of the assigned channels TRCH, APC and OW and reverse assigned pilot signal for any particular SU are fixed in proportion to each other and these channels are subject to nearly identical fading, therfore, they are power controlled together.

Adaptive Forward Power Control

The AFPC process attempts to maintain the minimum required SIR on the forward channels during a call/connection. The AFPC recursive process, shown in FIG. 27, consists of the steps of having an SU form the two error signals e_1 and e_2 in step **2701** where

$$e_1=P_d-(1+SNR_{REQ})P_N \tag{36}$$

$$e_2=P_r-P_o \tag{37}$$

and P_d is the despread signal plus noise power, P_N is the despread noise power, SNR_{REQ} is the required signal to noise ratio for the service type, P_r is a measure of the total received power, and P_o is the AGC set point. Next, the SU modem forms the combined error signal $\alpha_1e_1+\alpha_2e_2$ in step **2702**. Here, the weights α_1 and α_2 are chosen for each service type and APC update rate. In step **2703**, the SU hard limits the combined error signal and forms a single APC bit. The SU transmits the APC bit to the RCS in step **2704** and RCS modem receives the bit in step **2705**. The RCS increases or decreases its transmit power to the SU in step **2706** and the algorithm repeats starting from step **2701**.

Adaptive Reverse Power Control

The ARPC process maintains the minimum desired SIR on the reverse channels to minimize the total system reverse output power, during both call/connection establishment and while the call/connection is in progress. The recursive ARPC process, shown in FIG. 28, begins at step **2801** where the RCS modem forms the two error signals e_1 and e_2 in step **2801** where

$$e_1=P_d-(1+SNR_{REQ})P_N \tag{38}$$

$$e_2=P_{rt}-P_o \tag{39}$$

and P_d is the despread signal plus noise power, P_N is the despread noise power, SNR_{REQ} is the desired signal to noise ratio for the service type, P_{rt} is a measure of the average total power received by the RCS, and P_o is the AGC set point. The RCS modem forms the combined error signal $\alpha_1e_1+\alpha_2e_2$ in step **2802** and hard limits this error signal to determine a single APC bit in step **2803**. The RCS transmits the APC bit to the SU in step **2804**, and the bit is received by the SU in step **2805**. Finally, the SU adjusts its transmit power according to the received APC bit in step **2806**, and the algorithm repeats starting from step **2801**.

TABLE 14

Symbols/Thresholds Used for APC Computation

Service or Call Type	Call/ Connection Status	Symbol (and Threshold) Used for APC Decision
Don't care	Being Established	AXCH
ISDN D SU	In-Progress	one 1/64-kb/s symbol from TRCH (ISDN-D)
ISDN 1B + D SU	In-Progress	TRCH (ISDN-B)
ISDN 2B + D SU	In-Progress	TRCH (one ISDN-B)
POTS SU (64 KBPS PCM)	In-Progress	one 1/64-KBPS symbol from TRCH, use 64 KBPS PCM threshold
POTS SU (32 KBPS ADPCM)	In-Progress	one 1/64-KBPS symbol from TRCH, use 32 KBPS ADPCM threshold
Silent Maintenance Call (any SU)	In-Progress	OW (continuous during a maintenance call)

SIR and Multiple Channel Types

The required SIR for channels on a link is a function of channel format (e.g. TRCH, OW), service type (e.g. ISDN B. 32 KBPS ADPCM POTS), and the number of symbols over which data bits are distributed (e.g. two 64 kb/s symbols are integrated to form a single 32 kb/s ADPCM POTS symbol). Despreader output power corresponding to the required SIR for each channel and service type is predetermined. While a call/connection is in progress, several user CDMA logical channels are concurrently active; each of these channels transfers a symbol every symbol period. The SIR of the symbol from the nominally highest SIR channel is measured, compared to a threshold and used to determine the APC step up/down decision each symbol period. Table 14 indicates the symbol (and threshold) used for the APC computation by service and call type.

APC Parameters

APC information is always conveyed as a single bit of information, and the APC Data Rate is equivalent to the APC Update Rate. The APC update rate is 64 kb/s. This rate is high enough to accommodate expected Rayleigh and Doppler fades, and allow for a relatively high (~0.2) Bit Error Rate (BER) in the Uplink and Downlink APC channels, which minimizes capacity devoted to the APC.

The power step up/down indicated by an APC bit is nominally between 0.1 and 0.01 dB. The dynamic range for power control is 70 dB on the reverse link and 12 dB on the forward link for the exemplary embodiment of the present system.

An Alternative Embodiment of Multiplexing of APC information

The dedicated APC and OW logical channels described previously can also be multiplexed together in one logical

channel. The APC information is transmitted at 64 kb/s. continuously whereas the OW information occurs in data bursts. The alternative multiplexed logical channel includes the unencoded, non-interleaved 64 kb/s. APC information on, for example, the In-phase channel and the OW information on the Quadrature channel of the QPSK signal.

Closed Loop Power Control Implementation

The closed loop power control during a call connection responds to two different variations in overall system power. First, the system responds to local behavior such as changes in power level of an SU, and second, the system responds to changes in the power level of the entire group of active users in the system.

The Power Control system of the exemplary embodiment of the present invention is shown in FIG. 29. As shown, the circuitry used to adjust the transmitted power is similar for the RCS (shown as the RCS power control module **2901**) and SU (shown as the SU power control module **2902**). Beginning with the RCS power control module **2901**, the reverse link RF channel signal is received at the RF antenna and demodulated to produce the reverse CDMA signal RMCH. The signal RMCH is applied to the variable gain amplifier (VGA1) **2910** which produces an input signal to the Automatic Gain Control (AGC) Circuit **2911**. The AGC **2911** produces a variable gain amplifier control signal into the VGA1 **2910**. This signal maintains the level of the output signal of VGA1 **2910** at a near constant value. The output signal of VGA1 is despread by the despread-demultiplexer (demux) **2912**, which produces a despread user message signal MS and a forward APC bit. The forward APC bit is applied to the integrator **2913** to produce the Forward APC control signal. The Forward APC control signal controls the Forward Link VGA2 **2914** and maintains the Forward Link RF channel signal at a minimum desired level for communication.

The signal power of the despread user message signal MS of the RCS power module **2901** is measured by the power measurement Circuit **2915** to produce a signal power indication. The output of the VGA1 is also despread by the AUX despreader which despreads the signal by using an uncorrelated spreading code, and hence obtains a despread noise signal. The power measurement of this signal is multiplied by 1 plus the desired signal to noise ratio (SNR_R) to form the threshold signal S1. The difference between the despread signal power and the threshold value S1 is produced by the subtracter **2916**. This difference is the error signal ES1, which is an error signal relating to the particular SU transmit power level. Similarly, the control signal for the VGA1 **2910** is applied to the rate scaling circuit **2917** to reduce the rate of the control signal for VGA1 **2910**. The output signal of scaling circuit **2917** is a scaled system power level signal SP1. The Threshold Compute logic **2918** calculates the System Signal Threshold value SST from the RCS user channel power data signal RCSUSR. The complement of the Scaled system power level signal, SP1, and the System Signal Power Threshold value SST are applied to the adder **2919** which produces second error signal ES2. This error signal is related to the system transmit power level of all active SUs. The input Error signals ES1 and ES2 are combined in the combiner **2920** produce a combined error signal input to the delta modulator (DM1) **2921**, and the output signal of the DM1 is the reverse APC bit stream signal, having bits of value +1 or −1, which for the present invention is transmitted as a 64 kb/sec signal.

The Reverse APC bit is applied to the spreading circuit **2922**, and the output signal of the spreading circuit **2922** is the spread-spectrum forward APC message signal. Forward OW and Traffic signals are also provided to spreading circuits **2923**, **2924**, producing forward traffic message signals 1, 2, . . . N. The power level of the forward APC signal, the forward OW, and traffic message signals are adjusted by the respective amplifiers **2925**, **2926** and **2927** to produce the power level adjusted forward APC, OW, and TRCH channels signals. These signals are combined by the adder **2928** and applied to the VAG2 **2914**, which produces forward link RF channel signal.

The forward link RF channel signal including the spread forward APC signal is received by the RF antenna of the SU, and demodulated to produce the forward CDMA signal FMCH. This signal is provided to the variable gain amplifier (VGA3) **2940**. The output signal of VGA3 is applied to the Automatic Gain Control Circuit (AGC) **2941** which produces a variable gain amplifier control signal to VGA3 **2940**. This signal maintains the level of the output signal of VGA3 at a near constant level. The output signal of VAG3 **2940** is despread by the despread demux **2942**, which produces a despread user message signal SUMS and a reverse APC bit. The reverse APC bit is applied to the integrator **2943** which produces the Reverse APC control signal This reverse APC control signal is provided to the Reverse APC VGA4 **2944** to maintain the Reverse link RF channel signal at a minimum power level.

The despread user message signal SUMS is also applied to the power measurement circuit **2945** producing a power measurement signal, which is added to the complement of threshold value S2 in the adder **2946** to produce error signal ES3. The signal ES3 is an error signal relating to the RCS transmit power level for the particular SU. To obtain threshold S2, the despread noise power indication from the AUX despreader is multiplied by 1 plus the desired signal to noise ratio SNR_R. The AUX despreader despreads the input data using an uncorrelated spreading code, hence its output is an indication of the despread noise power.

Similarly, the control signal for the VGA3 is applied to the rate scaling circuit to reduce the rate of the control signal for VGA3 in order to produce a scaled received power level RP1 (see FIG. 29). The threshold compute circuit computes the received signal threshold RST from the SU measured power signal SUUSR. The complement of the scaled received power level RP1 and the received signal threshold RST are applied to the adder which produces error signal ES4. This error is related to the RCS transmit power to all other SUs. The input error signals ES3 and ES4 are combined in the combiner and input to the delta modulator DM2 **2947**. The output signal of DM2 **2947** is the forward APC bit stream signal, with bits having value of value +1 or −1. In the exemplary embodiment of the present invention, this signal is transmitted as a 64 kb/sec signal.

The Forward APC bit stream signal is applied to the spreading circuit **2948**, to produce the output reverse spread-spectrum APC signal. Reverse OW and Traffic signals are also input to spreading circuits **2949**, **2950**, producing reverse OW and traffic message signals 1, 2, . . . N, and the reverse pilot is generated by the reverse pilot generator **2951**. The power level of the reverse APC message signal, reverse OW message signal, reverse pilot, and the reverse traffic message signals are adjusted by amplifiers **2952**, **2953**, **2954**, **2955** to produce the signals which are combined by the adder **2956** and input to the reverse APC VGA4 **2944**. It is this VGA4 **2944** which produces the reverse link RF channel signal.

During the call connection and bearer channel establishment process, the closed loop power control of the present

invention is modified, and is shown in FIG. 30. As shown, the circuits used to adjust the transmitted power are different for the RCS, shown as the Initial RCS power control module 3001; and for the SU, shown as the Initial SU power control module 3002. Beginning with the Initial RCS power control module 3001, the reverse link RF channel signal is received at the RF antenna and demodulated producing the reverse CDMA signal IRMCH which is received by the first variable gain amplifier (VGA1) 3003. The output signal of VGA1 is detected by the Automatic Gain Control Circuit (AGC1) 3004 which provides a variable gain amplifier control signal to VGA1 3003 to maintain the level of the output signal of VAG1 at a near constant value. The output signal of VGA1 is despread by the despread demultiplexer 3005, which produces a despread user message signal IMS. The Forward APC control signal, ISET, is set to a fixed value, and is applied to the Forward Link Variable Gain Amplifier (VGA2) 3006 to set the Forward Link RF channel signal at a predetermined level.

The signal power of the despread user message signal IMS of the Initial RCS power module 3001 is measured by the power measure circuit 3007, and the output power measurement is subtracted from a threshold value S3 in the subtracter 3008 to produce error signal ES5, which is an error signal relating to the transmit power level of a particular SU. The threshold S3 is calculated by multiplying the despread power measurement obtained from the AUX despreader by 1 plus the desired signal to noise ratio SNR_R. The AUX despreader despreads the signal using an uncorrelated spreading code, hence its output signal is an indication of despread noise power. Similarly, the VGA1 control signal is applied to the rate scaling circuit 3009 to reduce the rate of the VGA1 control signal in order to produce a scaled system power level signal SP2. The threshold computation logic 3010 determines an Initial System Signal Threshold value (ISST) computed from the user channel power data signal (IRCSUSR). The complement of the Scaled system power level signal SP2 and the ISST are provided to the adder 3011 which produces a second error signal ES6, which is an error signal relating to the system transmit power level of all active SUs. The value of ISST is the desired transmit power for a system having the particular configuration. The input Error signals ES5 and ES6 are combined in the combiner 3012 produce a combined error signal input to the delta modulator (DM3) 3013. DM3 produces the initial reverse APC bit stream signal, having bits of value +1 or −1, which in the exemplary embodiment is transmitted as a 64 kb/s signal.

The Reverse APC bit stream signal is applied to the spreading circuit 3014, to produce the initial spread-spectrum forward APC signal. The CTCH information is spread by the spreader 3016 to form the spread CTCH message signal. The spread APC and CTCH signals are scaled by the amplifiers 3015 and 3017, and combined by the combiner 3018. The combined signal is applied to VAG2 3006, which produces the forward link RF channel signal.

The forward link RF channel signal including the spread forward APC signal is received by the RF antenna of the SU and demodulated to produce the initial forward CDMA signal (IFMCH) which is applied to the variable gain amplifier (VGA3) 3020. The output signal of VGA3 is detected by the Automatic Gain Control Circuit (AGC2) 3021 which produces a variable gain amplifier control signal for the VGA3 3020. This signal maintains the output power level of the VGA3 3020 at a near constant value. The output signal of VAG3 is despread by the despread demultiplexer 3022, which produces an initial reverse APC bit that is dependent on the output level of VGA3. The reverse APC bit is processed by the integrator 3023 to produce the Reverse APC control signal. The Reverse APC control signal is provided to the Reverse APC VGA4 3024 to maintain Reverse link RF channel signal at a defined power level.

The global channel AXCH signal is spread by the spreading circuits 3025 to provide the spread AXCH channel signal. The reverse pilot generator 3026 provides a reverse pilot signal, and the signal power of AXCH and the reverse pilot signal are adjusted by the respective amplifiers 3027 and 3028. The spread AXCH channel signal and the reverse pilot signal are summed by the adder 3029 to produce reverse link CDMA signal. The reverse link CDMA signal is received by the reverse APC VGA4 3024, which produces the reverse link RF channel signal output to the RF transmitter.

System Capacity Management

The system capacity management algorithm of the present invention optimizes the maximum user capacity for an RCS area, called a cell. When the SU comes within a certain value of minimum transmit power, the SU sends an alarm message to the RCS. The RCS sets the traffic lights which control access to the system, to "red" which, as previously described, is a flag that inhibits access by the SU's. This condition remains in effect until the call to the alarming SU terminates, or until the transmit power of the alarming SU, measured at the SU, is a value less than the maximum transmit power. When multiple SUs send alarm messages, the condition remains in effect until either all calls from alarming SUs terminate, or until the transmit power of the alarming SU, measured at the SU, is less than the maximum transmit power. An alternative embodiment monitors the bit error rate measurements from the FEC decoder, and holds the RCS traffic lights at "red" until the bit error rate is less than a predetermined value.

The blocking strategy of the present invention includes a method which uses the power control information transmitted from the RCS to an SU, and the received power measurements at the RCS. The RCS measures its transmit power level, detects that a maximum value is reached, and determines when to block new users. An SU preparing to enter the system blocks itself if the SU reaches the maximum transmit power before successful completion of a bearer channel assignment.

Each additional user in the system has the effect of increasing the noise level for all other users, which decreases the signal to noise ratio (SNR) that each user experiences. The power control algorithm maintains a desired SNR for each user. Therefore, in the absence of any other limitations, addition of a new user into the system has only a transient effect and the desired SNR is regained.

The transmit power measurement at the RCS is done by measuring either the root mean square (rms) value of the baseband combined signal or by measuring the transmit power of the RF signal and feeding it back to digital control circuits. The transmit power measurement may also be made by the SUs to determine if the unit has reached its maximum transmit power. The SU transmit power level is determined by measuring the control signal of the RF amplifier, and scaling the value based on the service type, such as POTS, FAX, or ISDN.

The information that an SU has reached the maximum power is transmitted to the RCS by the SU in a message on the Assigned Channels. The RCS also determines the condition by measuring reverse APC changes because, if the

RCS sends APC messages to the SU to increase SU transmit power, and the SU transmit power measured at the RCS is not increased, the SU has reached the maximum transmit power.

The RCS does not use traffic lights to block new users who have finished ramping-up using the short codes. These users are blocked by denying them the dial tone and letting them time out. The RCS sends all 1's (go down commands) on the APC Channel to make the SU lower its transmit power. The RCS also sends either no CTCH message or a message with an invalid address which would force the FSU to abandon the access procedure and start over. The SU, however, does not start the acquisition process immediately because the traffic lights are red.

When the RCS reaches its transmit power limit, it enforces blocking in the same manner as when an SU reaches its transmit power limit. The RCS turns off all the traffic lights on the FBCH, stats sending all 1 APC bits (go down commands) to those users who have completed their short code ramp-up but have not yet been given a dial tone, and either sends no CTCH message to these users or sends messages with invalid addresses to force them to abandon the access process.

The self blocking process of the SU is as follows. When the SU starts transmitting the AXCH, the APC starts its power control operation using the AXCH and the SU transmit power increases. While the transmit power is increasing under the control of the APC, it is monitored by the SU controller. If the transmit power limit is reached, the SU abandons the access procedure and starts over.

System Synchronization

The RCS is synchronized either to the PSTN Network Clock signal through one of the Line interfaces, as shown in FIG. 10, or to the RCS system clock oscillator, which free-runs to provide a master timing signal for the system. The Global Pilot Channel, and therefore all Logical channels within the CDMA channel, are synchronized to the system clock signal of the RCS. The Global Pilot (GLPT) is transmitted by the RCS and defines the timing at the RCS transmitter.

The SU receiver is synchronized to the GLPT, and so behaves as a slave to the Network Clock oscillator. However, the SU timing is retarded by the propagation delay. In the present embodiment of the invention, the SU modem extracts a 64 KHz and 8 KHz clock signal from the CDMA RF Receive channel, and a PLL oscillator circuit creates 2 MHz and 4 MHz clock signals

The SU transmitter and hence the LAXPT or ASPT are staved to the timing of the SU receiver.

The RCS receiver is synchronized to the LAXPT or the ASPT transmitted by the SU, however, its timing may be retarded by the propagation delay. Hence, the timing of the RCS receiver is that of the RCS transmitter retarded by twice the propagation delay.

Furthermore, the system can be synchronized via a reference received from a Global Positioning System receiver (GPS). In a system of this type, a GPS receiver in each RCS provides a reference clock signal to all submodules of the RCS. Because each RCS receives the same time reference from the GPS, all of the system clock signals in all of the RCSs are synchronized.

Although the invention has been described in terms of multiple exemplary embodiments, it is understood by those skilled in the art that the invention may be practiced with modifications to the embodiments that are within the scope of the invention as defined by the following claims.

APPENDIX A

0	75	150	225	300	375	450	525	600	675	750	825
1	76	151	226	301	376	451	526	601	676	751	826
2	77	152	227	302	377	452	527	602	677	752	827
3	78	153	228	303	378	453	528	603	678	753	828
4	79	154	229	304	379	454	529	604	679	754	829
5	80	155	230	305	380	455	530	605	680	755	830
6	81	156	231	306	381	456	531	606	681	756	831
7	82	157	232	307	382	457	532	607	682	757	832
8	83	158	233	308	383	458	533	608	683	758	833
9	84	159	234	309	384	459	534	609	684	759	834
10	85	160	235	310	385	460	535	610	685	760	835
11	86	161	236	311	386	461	536	611	686	761	836
12	87	162	237	312	387	462	537	612	687	762	837
13	88	163	238	313	388	463	538	613	688	763	838
14	89	164	239	314	389	464	539	614	689	764	839
15	90	165	240	315	390	465	540	615	690	765	840
16	91	166	241	316	391	466	541	616	691	766	841
17	92	167	242	317	392	467	542	617	692	767	842
18	93	168	243	318	393	468	543	618	693	768	843
19	94	169	244	319	394	469	544	619	694	769	844
20	95	170	245	320	395	470	545	620	695	770	845
21	96	171	246	321	396	471	546	621	696	771	846
22	97	172	247	322	397	472	547	622	697	772	847
23	98	173	248	323	398	473	548	623	698	773	848
24	99	174	249	324	399	474	549	624	699	774	849
25	100	175	250	325	400	475	550	625	700	775	850
26	101	176	251	326	401	476	551	626	701	776	851
27	102	177	252	327	402	477	552	627	702	777	852
28	103	178	253	328	403	478	553	628	703	778	853
29	104	179	254	329	404	479	554	629	704	779	854
30	105	180	255	330	405	480	555	630	705	780	855
31	106	181	256	331	406	481	556	631	706	781	856

-continued

APPENDIX A

32	107	182	257	332	407	482	557	632	707	782	857
33	108	183	258	333	408	483	558	633	708	783	858
34	109	184	259	334	409	484	559	634	709	784	859
35	110	185	260	335	410	485	560	635	710	785	860
36	111	186	261	336	411	486	561	636	711	786	861
37	112	187	262	337	412	487	562	637	712	787	862
38	113	188	263	338	413	488	563	638	713	788	863
39	114	189	264	339	414	489	564	639	714	789	864
40	115	190	265	340	415	490	565	640	715	790	865
41	116	191	266	341	416	491	566	641	716	791	866
42	117	192	267	342	417	492	567	642	717	792	867
43	118	193	268	343	418	493	568	643	718	793	868
44	119	194	269	344	419	494	569	644	719	794	869
45	120	195	270	345	420	495	570	645	720	795	870
46	121	196	271	346	421	496	571	646	721	796	871
47	122	197	272	347	422	497	572	647	722	797	872
48	123	198	273	348	423	498	573	648	723	798	873
49	124	199	274	349	424	499	574	649	724	799	874
50	125	200	275	350	425	500	575	650	725	800	875
51	126	201	276	351	426	501	576	651	726	801	876
52	127	202	277	352	427	502	577	652	727	802	877
53	128	203	278	353	428	503	578	653	728	803	878
54	129	204	279	354	429	504	579	654	729	804	879
55	130	205	280	355	430	505	580	655	730	805	880
56	131	206	281	356	431	506	581	656	731	806	881
57	132	207	282	357	432	507	582	657	732	807	882
58	133	208	283	358	433	508	583	658	733	808	883
59	134	209	284	359	434	509	584	659	734	809	884
60	135	210	285	360	435	510	585	660	735	810	885
61	136	211	286	-361	436	511	586	661	736	811	886
62	137	212	287	362	437	512	587	662	737	812	887
63	138	213	288	363	438	513	588	663	738	813	888
64	139	214	289	364	439	514	589	664	739	814	889
65	140	215	290	365	440	515	590	665	740	815	890
66	141	216	291	366	441	516	591	666	741	816	891
67	142	217	292	367	442	517	592	667	742	817	892
68	143	218	293	368	443	518	593	668	743	818	893
69	144	219	294	369	444	519	594	669	744	819	894
70	145	220	295	370	445	520	595	670	745	820	895
71	146	221	296	371	446	521	596	671	746	821	896
72	147	222	297	372	447	522	597	672	747	822	897
73	148	223	298	373	448	523	598	673	748	823	898
74	149	224	299	374	449	524	599	674	749	824	899
900	975	1050	22272302		2377	2452	2527	2602	2677	2752	2827
901	976	1051	22282303		2378	2453	2528	2603	2678	2753	2828
902	977	1052	22292304		2379	2454	2529	2604	2679	2754	2829
903	978	1053	22302305		2380	2455	2530	2605	2680	2755	2830
904	979	1054	22312306		2381	2456	2531	2606	2681	2756	2831
905	980	1055	22322307		2382	2457	2532	2607	2682	2757	2832
906	981	1056	22332308		2383	2458	2533	2608	2683	2758	2833
907	982	1057	22342309		2384	2459	2534	2609	2684	2759	2834
908	983	1058	22352310		2385	2460	2535	2610	2685	2760	2835
909	984	1059	22362311		2386	2461	2536	2611	2686	2761	2836
910	985	1060	22372312		2387	2462	2537	2612	2687	2762	2837
911	986	1061	22382313		2388	2463	2538	2613	2688	2763	2838
912	987	1062	22392314		2389	2464	2539	2614	2689	2764	2839
913	988	1063	22402315		2390	2465	2540	2615	2690	2765	2840
914	989	1064	22412316		2391	2466	2541	2616	2691	2766	2841
915	990	1065	22422317		2392	2467	2542	2617	2692	2767	2842
916	991	1066	22432318		2393	2468	2543	2618	2693	2768	2843
917	992	1067	22442319		2394	2469	2544	2619	2694	2769	2844
918	993	1068	22452320		2395	2470	2545	2620	2695	2770	2845
919	994	1069	22462321		2396	2471	2546	2621	2696	2771	2846
920	995	1070	22472322		2397	2472	2547	2622	2697	2772	2847
921	996	1071	22482323		2398	2473	2548	2623	2698	2773	2848
922	997	1072	22492324		2399	2474	2549	2624	2699	2774	2849
923	998	1073	22502325		2400	2475	2550	2625	2700	2775	2850
924	999	1074	22512326		2401	2476	2551	2626	2701	2776	2851
925	1000	1075	22522327		2402	2477	2552	2627	2702	2777	2852
926	1001	1076	22532328		2403	2478	2553	2628	2703	2778	2853
927	1002	1077	22542329		2404	2479	2554	2629	2704	2779	2854
928	1003	1078	22552330		2405	2480	2555	2630	2705	2780	2855
929	1004	1079	22562331		2406	2481	2556	2631	2706	2781	2856
930	1005	1080	22572332		2407	2482	2557	2632	2707	2782	2857
931	1006	1081	22582333		2408	2483	2558	2633	2708	2783	2858
932	1007	1082	22592334		2409	2484	2559	2634	2709	2784	2859
933	1008	1083	22602335		2410	2485	2560	2635	2710	2785	2860

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APPENDIX A

934	1009	1084	2261	2336	2411	2486	2561	2636	2711	2786	2861
935	1010	1085	2262	2337	2412	2487	2562	2637	2712	2787	2862
936	1011	1086	2263	2338	2413	2488	2563	2638	2713	2788	2863
937	1012	1087	2264	2339	2414	2489	2564	2639	2714	2789	2864
938	1013	1088	2265	2340	2415	2490	2565	2640	2715	2790	2865
939	1014	1089	2266	2341	2416	2491	2566	2641	2716	2791	2866
940	1015	1090	2267	2342	2417	2492	2567	2642	2717	2792	2867
941	1016	1091	2268	2343	2418	2493	2568	2643	2718	2793	2868
942	1017	1092	2269	2344	2419	2494	2569	2644	2719	2794	2869
943	1018	1093	2270	2345	2420	2495	2570	2645	2720	2795	2870
944	1019	1094	2271	2346	2421	2496	2571	2646	2721	2796	2871
945	1020	1095	2272	2347	2422	2497	2572	2647	2722	2797	2872
946	1021	1096	2273	2348	2423	2498	2573	2648	2723	2798	2873
947	1022	1097	2274	2349	2424	2499	2574	2649	2724	2799	2874
948	1023	1098	2275	2350	2425	2500	2575	2650	2725	2800	2875
949	1024	1099	2276	2351	2426	2501	2576	2651	2726	2801	2876
950	1025	1100	2277	2352	2427	2502	2577	2652	2727	2802	2877
951	1026	1101	2278	2353	2428	2503	2578	2653	2728	2803	2878
952	1027	2204	2279	2354	2429	2504	2579	2654	2729	2804	2879
953	1028	2205	2280	2355	2430	2505	2580	2655	2730	2805	2880
954	1029	2206	2281	2356	2431	2506	2581	2656	2731	2806	2881
955	1030	2207	2282	2357	2432	2507	2582	2657	2732	2807	2882
956	1031	2208	2283	2358	2433	2508	2583	2658	2733	2808	2883
957	1032	2209	2284	2359	2434	2509	2584	2659	2734	2809	2884
958	1033	2210	2285	2360	2435	2510	2585	2660	2735	2810	2885
959	1034	2211	2236	2361	2436	2511	2586	2661	2736	2811	2886
960	1035	2212	2237	2362	2437	2512	2587	2662	2737	2812	2887
961	1036	2213	2288	2363	2438	2513	2588	2663	2738	2813	2888
962	1037	2214	2289	2364	2439	2514	2589	2664	2739	2814	2889
963	1038	2215	2290	2365	2440	2515	2590	2665	2740	2815	2890
964	1039	2216	2291	2366	2441	2516	2591	2666	2741	2816	2891
965	1040	2217	2292	2367	2442	2517	2592	2667	2742	2817	2892
966	1041	2218	2293	2368	2443	2518	2593	2668	2743	2818	2893
967	1042	2219	2294	2369	2444	2519	2594	2669	2744	2819	2894
968	1043	2220	2295	2370	2445	2520	2595	2670	2745	2820	2895
969	1044	2221	2296	2371	2446	2521	2596	2671	2746	2821	2896
970	1045	2222	2297	2372	2447	2522	2597	2672	2747	2822	2897
971	1046	2223	2298	2373	2448	2523	2598	2673	2748	2823	2898
972	1047	2224	2299	2374	2449	2524	2599	2674	2749	2824	2899
973	1048	2225	2300	2375	2450	2525	2600	2675	2750	2825	2900
974	1049	2226	2301	2376	2451	2526	2601	2676	2751	2826	2901
2902	2977	3052	3127	3202	3277	4454	4529	4604	4679	4754	4829
2903	2978	3053	3128	3203	3278	4455	4530	4605	4680	4755	4830
2904	2979	3054	3129	3204	3279	4456	4531	4606	4681	4756	4831
2905	2980	3055	3130	3205	3280	4457	4532	4607	4682	4757	4832
2906	2981	3056	3131	3206	3281	4458	4533	4608	4683	4758	4833
2907	2982	3057	3132	3207	3282	4459	4534	4609	4684	4759	4834
2908	2983	3058	3133	3208	3283	4460	4535	4610	4685	4760	4835
2909	2984	3059	3134	3209	3284	4461	4536	4611	4686	4761	4836
2910	2985	3060	3135	3210	3285	4462	4537	4612	4687	4762	4837
2911	2986	3061	3136	3211	3286	4463	4538	4613	4688	4763	4838
2912	2987	3062	3137	3212	3287	4464	4539	4614	4689	4764	4839
2913	2988	3063	3138	3213	3288	4465	4540	4615	4690	4765	4840
2914	2989	3064	3139	3214	3289	4466	4541	4616	4691	4766	4841
2915	2990	3065	3140	3215	3290	4467	4542	4617	4692	4767	4842
2916	2991	3066	3141	3216	3291	4468	4543	4618	4693	4768	4843
2917	2992	3067	3142	3217	3292	4469	4544	4619	4694	4769	4844
2918	2993	3068	3143	3218	3293	4470	4545	4620	4695	4770	4845
2919	2994	3069	3144	3219	3294	4471	4546	4621	4696	4771	4846
2920	2995	3070	3145	3220	3295	4472	4547	4622	4697	4772	4847
2921	2996	3071	3146	3221	3296	4473	4548	4623	4698	4773	4848
2922	2997	3072	3147	3222	3297	4474	4549	4624	4699	4774	4849
2923	2998	3073	3148	3223	3298	4475	4550	4625	4700	4775	4850
2924	2999	3074	3149	3224	3299	4476	4551	4626	4701	4776	4851
2925	3000	3075	3150	3225	3300	4477	4552	4627	4702	4777	4852
2926	3001	3076	3151	3226	3301	4478	4553	4628	4703	4778	4853
2927	3002	3077	3152	3227	3302	4479	4554	4629	4704	4779	4854
2928	3003	3078	3153	3228	3303	4480	4555	4630	4705	4780	4855
2929	3004	3079	3154	3229	3304	4481	4556	4631	4706	4781	4856
2930	3005	3080	3155	3230	3305	4482	4557	4632	4707	4782	4857
2931	3006	3081	3156	3231	4408	4483	4558	4633	4708	4783	4858
2932	3007	3082	3157	3232	4409	4484	4559	4634	4709	4784	4859
2933	3008	3083	3158	3233	4410	4485	4560	4635	4710	4785	4860
2934	3009	3084	3159	3234	4411	4486	4561	4636	4711	4786	4861
2935	3010	3085	3160	3235	4412	4487	4562	4637	4712	4787	4862
2936	3011	3086	3161	3236	4413	4488	4563	4638	4713	4788	4863
2937	3012	3087	3162	3237	4414	4489	4564	4639	4714	4789	4864

-continued

APPENDIX A

2938	3013	3088	3163	3238	4415	4490	4565	4640	4715	4790	4865
2939	3014	3089	3164	3239	4416	4491	4566	4641	4716	4791	4866
2940	3015	3090	3165	3240	4417	4492	4567	4642	4717	4792	4867
2941	3016	3091	3166	3241	4418	4493	4568	4643	4718	4793	4868
2942	3017	3092	3167	3242	4419	4494	4569	4644	4719	4794	4869
2943	3018	3093	3168	3243	4420	4495	4570	4645	4720	4795	4870
2944	3019	3094	3169	3244	4421	4496	4571	4646	4721	4796	4871
2945	3020	3095	3170	3245	4422	4497	4572	4647	4722	4797	4872
2946	3021	3096	3171	3246	4423	4498	4573	4648	4723	4798	4873
2947	3022	3097	3172	3247	4424	4499	4574	4649	4724	4799	4874
2948	3023	3098	3173	3248	4425	4500	4575	4650	4725	4800	4875
2949	3024	3099	3174	3249	4426	4501	4576	4651	4726	4801	4876
2950	3025	3100	3175	3250	4427	4502	4577	4652	4727	4802	4877
2951	3026	3101	3176	3251	4428	4503	4578	4653	4728	4803	4878
2952	3027	3102	3177	3252	4429	4504	4579	4654	4729	4304	4879
2953	3028	3103	3178	3253	4430	4505	4580	4655	4730	4805	4880
2954	3029	3104	3179	3254	4431	4506	4581	4656	4731	4806	4881
2955	3030	3105	3180	3255	4432	4507	4582	4657	4732	4807	4882
2956	3031	3106	3181	3256	4433	4508	4583	4658	4733	4808	4883
2957	3032	3107	3182	3257	4434	4509	4584	4659	4734	4809	4884
2958	3033	3108	3183	3258	4435	4510	4585	4660	4735	4810	4885
2959	3034	3109	3184	3259	4436	4511	4586	4661	4736	4811	4886
2960	3035	3110	3185	3260	4437	4512	4587	4662	4737	4812	4887
2961	3036	3111	3186	3261	4438	4513	4588	4663	4738	4813	4888
2962	3037	3112	3187	3262	4439	4514	4589	4664	4739	4314	4889
2963	3038	3113	3183	3263	4440	4515	4590	4665	4740	4815	4890
2964	3039	3114	3189	3264	4441	4516	4591	4666	4741	4816	4891
2965	3040	3115	3190	3265	4442	4517	4592	4667	4742	4817	4892
2966	3041	3116	3191	3266	4443	4518	4593	4668	4743	4818	4893
2967	3042	3117	3192	3267	4444	4519	4594	4669	4744	4819	4894
2968	3043	3118	3193	3268	4445	4520	4595	4670	4745	4820	4895
2969	3044	3119	3194	3269	4446	4521	4596	4671	4746	4821	4896
2970	3045	3120	3195	3270	4447	4522	4597	4672	4747	4822	4897
2971	3046	3121	3196	3271	4448	4523	4598	4673	4748	4823	4898
2972	3047	3122	3197	3272	4449	4524	4599	4674	4749	4824	4899
2973	3048	3123	3198	3273	4450	4525	4600	4675	4750	4825	4900
2974	3049	3124	3199	3274	4451	4526	4601	4676	4751	4826	4901
2975	3050	3125	3200	3275	4452	4527	4602	4677	4752	4827	4902
2976	3051	3126	3201	3276	4453	4528	4603	4678	4753	4828	4903
4904	4979	5054	5129	5204	5279	5354	5429	5504	6681	6756	6831
4905	4980	5055	5130	5205	5280	5355	5430	5505	6682	6757	6832
4906	4981	5056	5131	5206	5281	5356	5431	5506	6683	6728	6833
4907	4982	5057	5132	5207	5282	5357	5432	5507	6684	6759	6834
4908	4983	5058	5133	5208	5283	5358	5433	5508	6685	6760	6835
4909	4984	5059	5134	5209	5284	5359	5434	5509	6686	6761	6836
4910	4985	5060	5135	5210	5285	5360	5435	6612	6687	6762	6837
4911	4986	5061	5136	5211	5286	5361	5436	6613	6688	6763	6838
4912	4987	5062	5137	5212	5287	5362	5437	6614	6689	6764	6839
4913	4988	5063	5138	5213	5288	5363	5438	6615	6690	6765	6840
4914	4989	5064	5139	5214	5289	5364	5439	6616	6691	6766	6841
4915	4990	5065	5140	5215	5290	5365	5440	6617	6692	6767	6842
4916	4991	5066	5141	5216	5291	5366	5441	6615	6693	6768	6843
4917	4992	5067	5142	5217	5292	5367	5442	6619	6694	6769	6844
4915	4993	5068	5143	5218	5293	5368	5443	6620	6695	6770	6845
4919	4994	5069	5144	5219	5294	5369	5444	6621	6696	6771	6846
4920	4995	5070	5145	5220	5295	5370	5445	6622	6697	6772	6847
4921	4996	5071	5146	5221	5296	5371	5446	6623	6698	6773	6848
4922	4997	5072	5147	5222	5297	5372	5447	6624	6699	6774	6849
4923	4995	5073	5148	5223	5298	5373	5448	6625	6700	6775	6850
4924	4999	5074	5149	5224	5299	5374	5449	6626	6701	6776	6551
4925	5000	5075	5150	5225	5300	5375	5450	6627	6702	6777	6852
4926	5001	5076	5151	5226	5301	5376	5451	6628	6703	6778	6853
4927	5002	5077	5152	5227	5302	5377	5452	6629	6704	6779	6854
4928	5003	5078	5153	5228	5303	5378	5453	6630	6705	6780	6855
4929	5004	5079	5154	5229	5304	5379	5454	6631	6706	6781	6856
4930	5005	5080	5155	5230	5305	5380	5455	6632	6707	6782	6857
4931	5006	5081	5156	5231	5306	5381	5456	6633	6708	6783	6858
4932	5007	5082	5157	5232	5307	5382	5457	6634	6709	6784	6859
4933	5008	5083	5158	5233	5308	5383	5458	6635	6710	6755	6860
4934	5009	5084	5159	5234	5309	5384	5459	6636	6711	6786	6861
4935	5010	5085	5160	5235	5310	5385	5460	6637	6712	6787	6862
4936	5011	5086	5161	5236	5311	5386	5461	6638	6713	6788	6863
4937	5012	5087	5162	5237	5312	5387	5462	6639	6714	6789	6564
4938	5013	5088	5163	5238	5313	5388	5463	6640	6715	6790	6865
4939	5014	5089	5164	5239	5314	5389	5464	6641	6716	6791	6866
4940	5015	5090	5165	5240	5315	5390	5465	6642	6717	6792	6867
4941	5016	5091	5166	5241	5316	5391	5466	6643	6718	6793	6868

-continued

APPENDIX A

4942	5017	5092	5167	5242	5317	5392	5467	6644	6719	6794	6869
4943	5018	5093	5168	5243	5318	5393	5468	6645	6720	6795	6870
4944	5019	5094	5169	5244	5319	5394	5469	6646	6721	6796	6871
4945	5020	5095	5170	5245	5320	5395	5470	6647	6722	6797	6872
4946	5021	5096	5171	5246	5321	5396	5471	6648	6723	6798	6873
4947	5022	5097	5172	5247	5322	5397	5472	6649	6724	6799	6874
4948	5023	5095	5173	5248	5323	5398	5473	6650	6725	6800	6875
4949	5024	5099	5174	5249	5324	5399	5474	6651	6726	6801	6876
4950	5025	5100	5175	5250	5325	5400	5475	6652	6727	6802	6877
4951	5026	5101	5176	5251	5326	5401	5476	6653	6728	6803	6878
4952	5027	5102	5177	5252	5327	5402	5477	6654	6729	6804	6879
4953	5028	5103	5178	5253	5325	5403	5478	6655	6730	6805	6880
4954	5029	5104	5179	5254	5329	5404	5479	6656	6731	6806	6881
4955	5030	5105	5180	5255	5330	5405	5480	6657	6732	6807	6882
4956	5031	5106	5181	5256	5331	5406	5481	6658	6733	6808	6883
4957	5032	5107	5182	5257	5332	5407	5482	6659	6734	6809	6884
4958	5033	5108	5153	5258	5333	5408	5483	6660	6735	6810	6885
4959	5034	5109	5184	5259	5334	5409	5484	6661	6736	6811	6886
4960	5035	5110	5185	5260	5335	5410	5485	6662	6737	6812	6887
4961	5036	5111	5186	5261	5336	5411	5486	6663	6738	6813	6888
4962	5037	5112	5187	5262	5337	5412	5487	6664	6739	6814	6889
4963	5038	5113	5158	5263	5338	5413	5488	6665	6740	6815	6890
4964	5039	5114	5159	5264	5339	5414	5489	6666	6741	6816	6891
4965	5040	5115	5190	5265	5340	5415	5490	6667	6742	6817	6592
4966	5041	5116	5191	5266	5341	5416	5491	6668	6743	6818	6893
4967	5042	5117	5192	5267	5342	5417	5492	6669	6744	6819	6894
4968	5043	5118	5193	5268	5343	5418	5493	6670	6745	6820	6895
4969	5044	5119	5194	5269	5344	5419	5494	6671	6746	6821	6896
4970	5045	5120	5195	5270	5345	5420	5495	6672	6747	6822	6897
4971	5046	5121	5196	5271	5346	5421	5496	6673	6748	6823	6898
4972	5047	5122	5197	5272	5347	5422	5497	6674	6749	6824	6899
4973	5048	5123	5198	5273	5348	5423	5498	6675	6750	6825	6900
4974	5049	5124	5199	5274	5349	5424	5499	6676	6751	6826	6901
4975	5050	5125	5200	5275	5350	5425	5500	6677	6752	6827	6902
4976	5051	5126	5201	5276	5351	5426	5501	6678	6753	6828	6903
4977	5052	5127	5202	5277	5352	5427	5502	6679	6754	6529	6904
4978	5053	5128	5203	5278	5353	5428	5503	6680	6755	6830	6905
6906	6930	6954	6978	7002	7026	7050	7074	7098	7122	7146	7170
6907	6931	6955	6979	7003	7027	7051	7075	7099	7123	7147	7171
6908	6932	6956	6980	7004	7028	7052	7076	7100	7124	7148	7172
6909	6933	6957	6981	7005	7029	7053	7077	7101	7125	7149	7173
6910	6934	6958	6982	7006	7030	7054	7078	7102	7126	7150	7174
6911	6935	6959	6983	7007	7031	7055	7079	7103	7127	7151	7175
6912	6936	6960	6984	7008	7032	7056	7080	7104	7128	7152	7176
6913	6937	6961	6985	7009	7033	7057	7081	7105	7129	7153	7177
6914	6938	6962	6986	7010	7034	7058	7082	7106	7130	7154	7178
6915	6939	6963	6987	7011	7035	7059	7083	7107	7131	7155	7179
6916	6940	6964	6988	7012	7036	7060	7084	7108	7132	7156	7180
6917	6941	6965	6989	7013	7037	7061	7085	7109	7133	7157	7181
6918	6942	6966	6990	7014	7038	7062	7086	7110	7134	7158	7182
6919	6943	6967	6991	7015	7039	7063	7087	7111	7135	7159	7183
6920	6944	6968	6992	7016	7040	7064	7088	7112	7136	7160	7184
6921	6945	6969	6993	7017	7041	7065	7089	7113	7137	7161	
6922	6946	6970	6994	7018	7042	7066	7090	7114	7138	7162	
6923	6947	6971	6995	7019	7043	7067	7091	7115	7139	7163	
6924	6948	6972	6996	7020	7044	7068	7092	7116	7140	7164	
6925	6949	6973	6997	7021	7045	7069	7093	7117	7141	7165	
6926	6950	6974	6998	7022	7046	7070	7094	7118	7142	7166	
6927	6951	6975	6999	7023	7047	7071	7095	7119	7143	7167	
6928	6952	6976	7000	7024	7048	7072	7096	7120	7144	7168	
6929	6953	6977	7001	7025	7049	7073	7097	7121	7145	7169	

The invention claimed is:

1. A bearer channel modification system for a multiple access spread-spectrum communication system including a plurality of information signals each having several different channel rates which information signals are transmitted as a plurality of message code channels over an Radio Frequency (RF) channel as a Code Division Multiplexed (CDM) signal, each of the plurality of message code channels being able to convey information at a predetermined information channel rate, the system comprising

means for providing a plurality of call type signals corresponding to the information signal rates for the information signals;

a transmitter including a first information channel mode modification means responsive to the call type signal for changing the information signal from a first one of the message code signals to a second one of the message code signals which second message code signal has a different information channel rate than the first message code signal; and

a receiver including a second information channel mode modification means responsive to the call type signal

for changing a received information signal from the first message code signal to the second message code signal to receive the information signal at the different information channel rate.

2. A bearer channel modification system according to claim 1 wherein the transmitter further includes means for sequentially a) sending the message data combined with the first message code signal to the substantial exclusion of the second message code signal, b) concurrently sending the message data combined with the first message code signal and the message data combined with the second message code signal and c) sending the message data combined with the second message code signal to the substantial exclusion of the first message code signal.

3. A bearer channel modification system according to claim 1 wherein the transmitter further includes:

means for synchronizing the transmitter to the receiver on a sub-epoch boundary;

means for sending the message signal combined with the first message code signal prior to the sub-epoch boundary and for sending the message signal combined with the second message code signal to the substantial exclusion of the first message code signal subsequent to the sub-epoch boundary.

4. A multiple access spread-spectrum communication system for dynamically changing a transmission rate of a plurality of information signals received simultaneously over telecommunication lines by a base station and transmitted to a subscriber through a plurality of spread-spectrum message channels, the system comprising

a) a base station, connected to a remote call-processor which provides a call type signal identifying an information signal rate of the respective information signal and a conversion method for the respective information signal; comprising:

a system channel controller which assigns each of the information signals and call type signals to a respective spread-spectrum message channel;

first information channel mode modification means connected to the system channel controller and responsive to the call type signal for changing the combination of the respective information signal from one spread-spectrum message channel to another pre-determined spread-spectrum message channel which supports a different information channel rate; and

b) a subscriber unit comprising:

a plurality of despreading means, each of the despreading means for recovering a respective one of the information signals and a respective one of the call type signals from a respective one of the spread-spectrum message channels;

second information channel mode modification means responsive to the call type signal for selectively assigning one of the despreading means to a respective one of the spread spectrum message channels which supports the different information rate; and a signal conversion means responsive to the call type signal for selectively converting the despread information signal into a digital data signal.

5. A bearer channel modification system for a multiple access spread-spectrum communication system including a plurality of information signals each having a respective rate, the system comprising

a plurality of message code channels, each of the channels being able to convey information at a respective pre-determined information channel rate, wherein an information signal is transmitted as at least one message code channel as a Code Division Multiplexed (CDM) signal

means for providing a plurality of call type signals corresponding to the information signal rates for the information signals;

a transmitter including a first information channel mode modification means responsive to the call type signal for changing the information signal from a first one of the message code signals to a second one of the message code signals which second message code signal has a respective information channel rate; and

a receiver including a second information channel mode modification means responsive to the call type signal for changing a received information signal from the first message code signal to the second message code signal to receive the information signal at the respective information channel rate.

6. A bearer channel modification system according to claim 5 further including:

means, coupled to the transmitter, for changing the predetermined information channel rate of at least one of the message code channels from a first rate to a second rate; and

means, coupled to the receiver and responsive to a signal provided by the transmitter for conditioning the receiver to receive the information signal provided via the one message code channel at the first rate before the predetermined information channel rate is changed and at the second rate after the predetermined information channel rate is changed.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

ATENT NO. : 6,215,778 B1
ATED : April 10, 2001
IVENTOR(S) : Lomp et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 8,
Line 59, delete "OF" and insert thereof -- RF --.

Column 10,
Line 18, before "M-ary Phase Shift Keying", delete "MSK" and insert therefor -- MPSK --.

Column 11,
Line 26, delete "SH" and insert therefor -- SHF --.
Line 28, delete "MS" and insert therefor -- MHZ --.

Column 12,
Line 28, delete "PC" and insert therefor -- MPC --.

Column 14,
Line 64, delete "(LAW" and insert therefor -- (LAXPT) --.

Column 15,
Line 36, delete "ARCH" and insert therefor -- TRCH --.

Column 17,
Line 58, delete "sequenced" and insert therefor -- sequences --.

Column 18,
Line 42, delete "x^1" and insert therefor -- 1 --.
Line 62, delete "6" and insert therefor -- δ --.

Column 22,
Line 54, delete "C3C*" and insert therefor -- $C3 \oplus C^*$ --.

Column 27,
Line 56, delete "$P_{Tc}(i)$" and insert therefor -- $P_{Tc}(t)$ --.

Column 33,
Line 57, delete "c((n+i))" and insert therefor -- c((n+i)T) --.

Column 34,
Line 1, delete "AMP" and insert therefor -- AMF --.

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,215,778 B1
DATED : April 10, 2001
INVENTOR(S) : Lomp et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 38,
Line 59, delete "Bach" and insert therefor -- Each --.

Column 40,
Lines 31 and 58, delete "MW" and insert therefor -- MIU --.

Column 45,
Line 10, delete "AID" and insert therefor -- A/D --.
Line 66, delete "AMP" and insert therefor -- AMF --.

Column 46,
Line 7, delete "AID" and insert therefor -- A/D --.

Column 48,
Lines 44, 45 and 55, delete "AMP" and insert therefor -- AMF --.

Column 50,
Line 33, delete "[m]" and insert therefor -- [k] --.

Column 58,
Line 64, delete "CPM" and insert therefor -- CFM --.

Column 72,
Line 17, delete "staved" and insert therefor -- slaved --.

Column 73,
Line 30, delete "-361" and insert therefor -- 361 --.

Signed and Sealed this

Twenty-sixth Day of November, 2002

Attest:

JAMES E. ROGAN

Attesting Officer *Director of the United States Patent and Trademark Office*

US005179572A

United States Patent [19]

Schilling

[11] Patent Number: 5,179,572

[45] Date of Patent: Jan. 12, 1993

[54] SPREAD SPECTRUM CONFERENCE CALLING SYSTEM AND METHOD

[75] Inventor: Donald L. Schilling, Sands Point, N.Y.

[73] Assignee: SCS Mobilecom, Inc., Port Washington, N.Y.

[21] Appl. No.: 715,835

[22] Filed: Jun. 17, 1991

[51] Int. Cl.[5] H04L 27/30

[52] U.S. Cl. 375/1

[58] Field of Search 375/1

[56] References Cited

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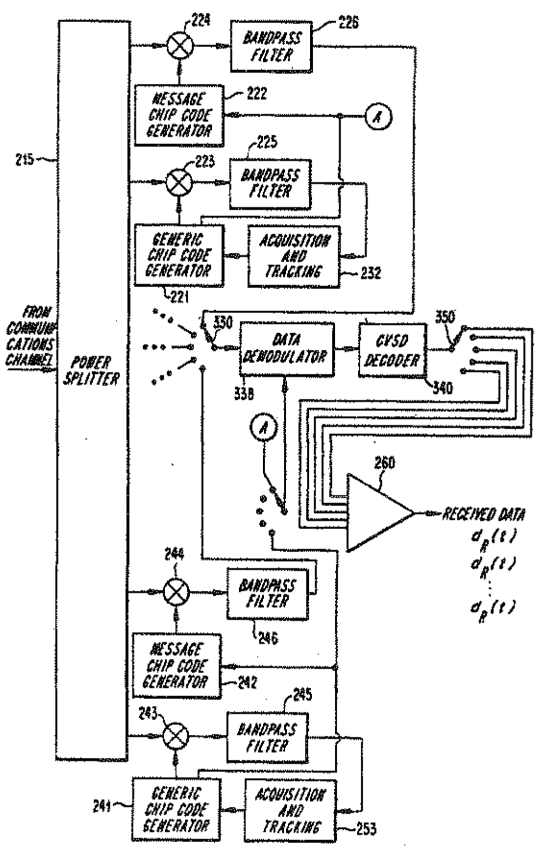
5,031,173	7/1991	Short et al.	375/1

Primary Examiner—Salvatore Cangialosi
Attorney, Agent, or Firm—David Newman & Associates

[57] ABSTRACT

A spread-spectrum-conference-calling receiver, for use over a communications channel. At each of a plurality of spread-spectrum transmitters, a transmitter-generic-chip-code generator generates a generic-chip-code signal and a transmitter-message-chip-code generator generates a message-chip-code signal. An EXCLUSIVE-OR gate spread-spectrum processes message data with the message-chip-code signal to generate a spread-spectrum signal. The combiner combines the generic-chip-code signal and the spread-spectrum-processed signal. A plurality of receiver-generic-chip-code generators generate a plurality of replicas of the generic-chip-code signal. Each receiver-generic mixer recovers a carrier signal from one of the plurality of received spread-spectrum-communications signals. A plurality of receiver-message-chip-code generators generate a plurality of replica of the message-chip-code signals. A plurality of receiver-message mixers despread one of the plurality of received spread-spectrum-communications signal as a modulated-data signal. Tracking and acquistion circuits use the recovered carrier signal for synchronizing the replicas of the generic-chip-code signals to the recovered carrier signals, respectively. An envelope detector demodulates the modulated-data signal as a demodulated signal.

15 Claims, 5 Drawing Sheets



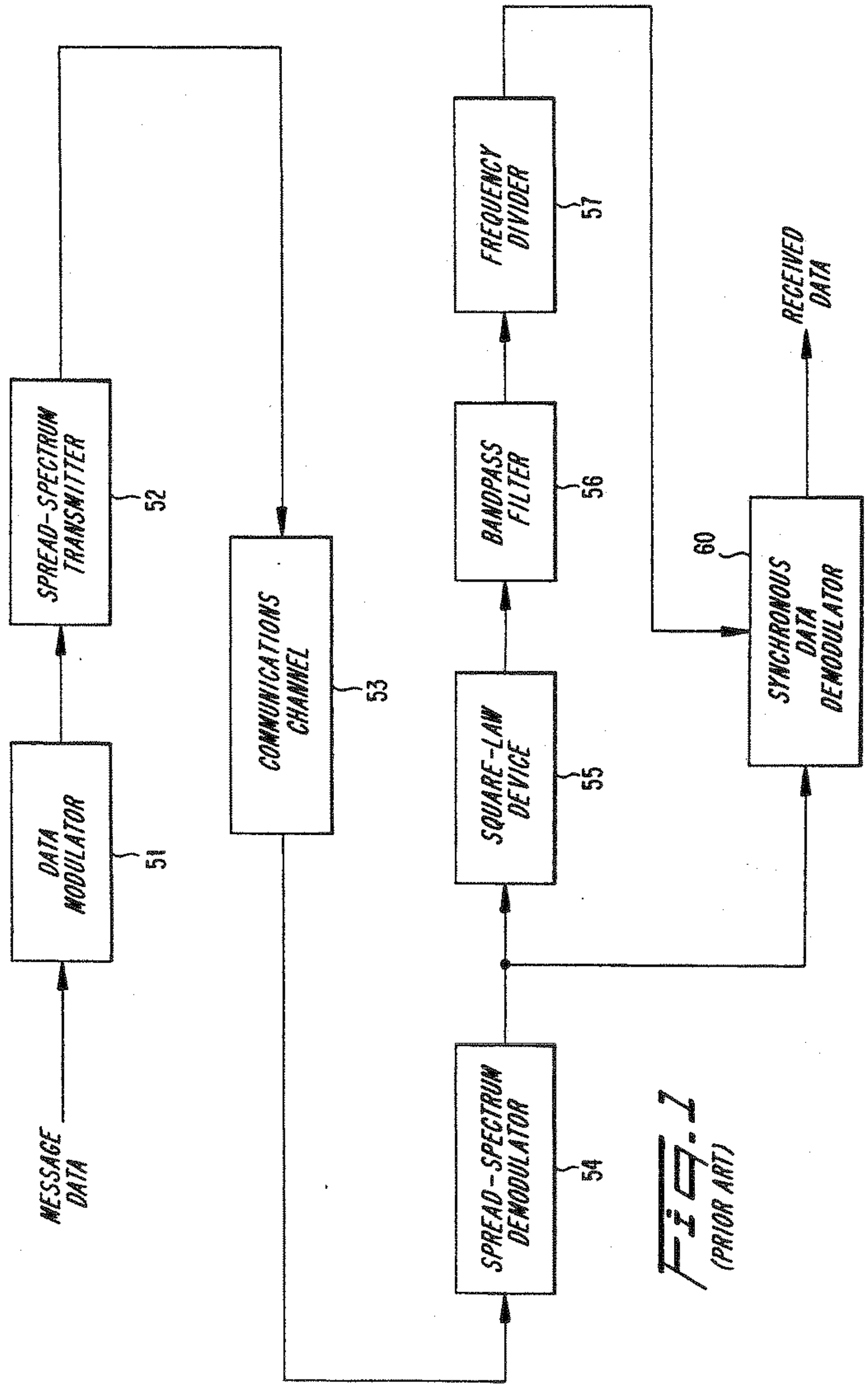


FIG. 1 (PRIOR ART)

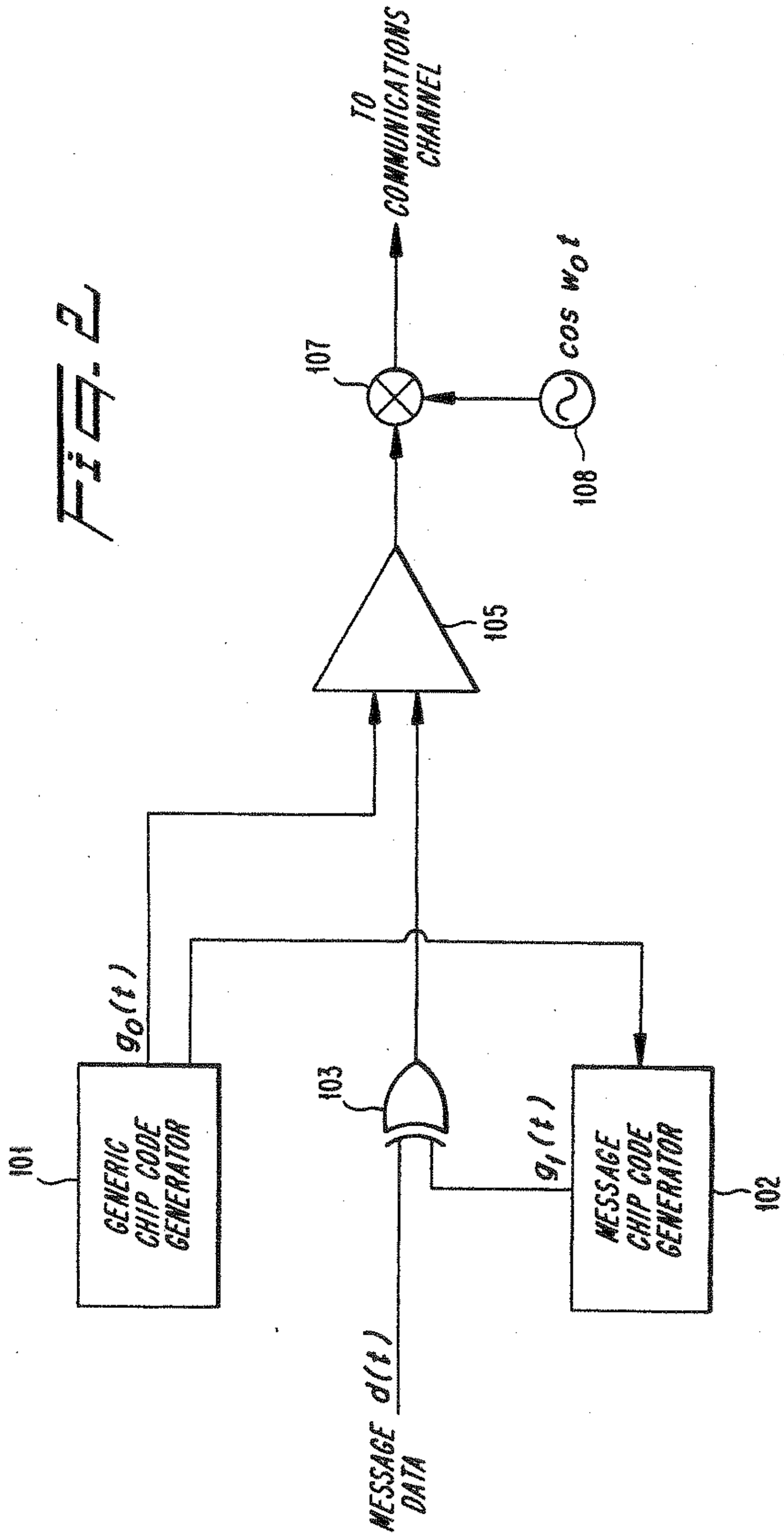
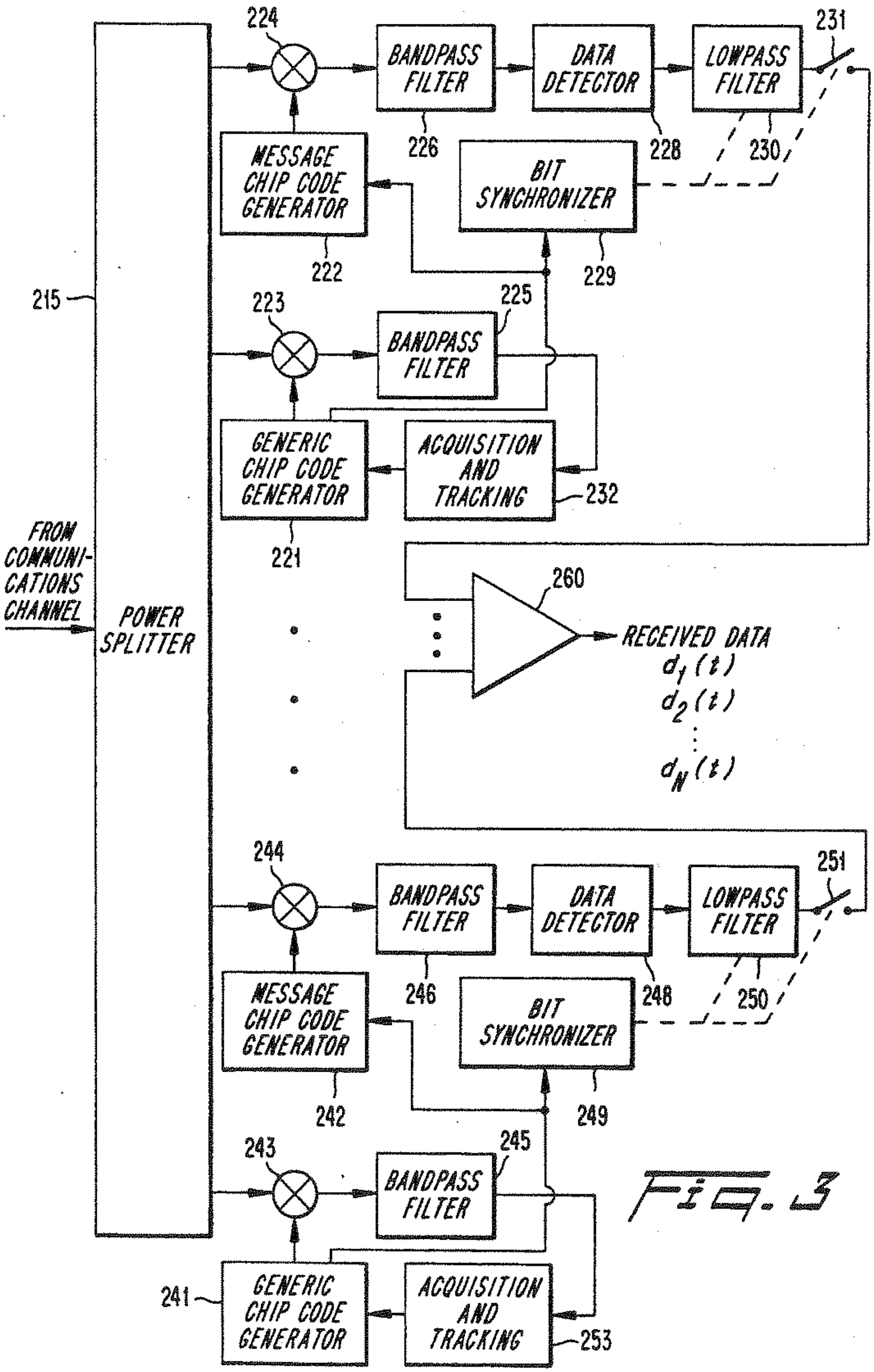

TO
COMMUNICATIONS
CHANNEL
107
cos $w_0 t$
108
105
$g_0(t)$
101
GENERIC
CHIP CODE
GENERATOR
103
$g_1(t)$
MESSAGE
CHIP CODE
GENERATOR
102
MESSAGE
DATA
$d(t)$

FIG. 2



224
BANDPASS FILTER
DATA DETECTOR
LOWPASS FILTER
231
MESSAGE CHIP CODE GENERATOR
226
228
230
BIT SYNCHRONIZER
222
229
215
223
225
BANDPASS FILTER
GENERIC CHIP CODE GENERATOR
ACQUISITION AND TRACKING
232
221
FROM COMMUNI-CATIONS CHANNEL
POWER SPLITTER
260
RECEIVED DATA
$d_1(t)$
$d_2(t)$
$d_N(t)$
244
BANDPASS FILTER
DATA DETECTOR
LOWPASS FILTER
251
MESSAGE CHIP CODE GENERATOR
246
248
250
BIT SYNCHRONIZER
242
249
243
245
BANDPASS FILTER
241
GENERIC CHIP CODE GENERATOR
ACQUISITION AND TRACKING
253

FIG. 3

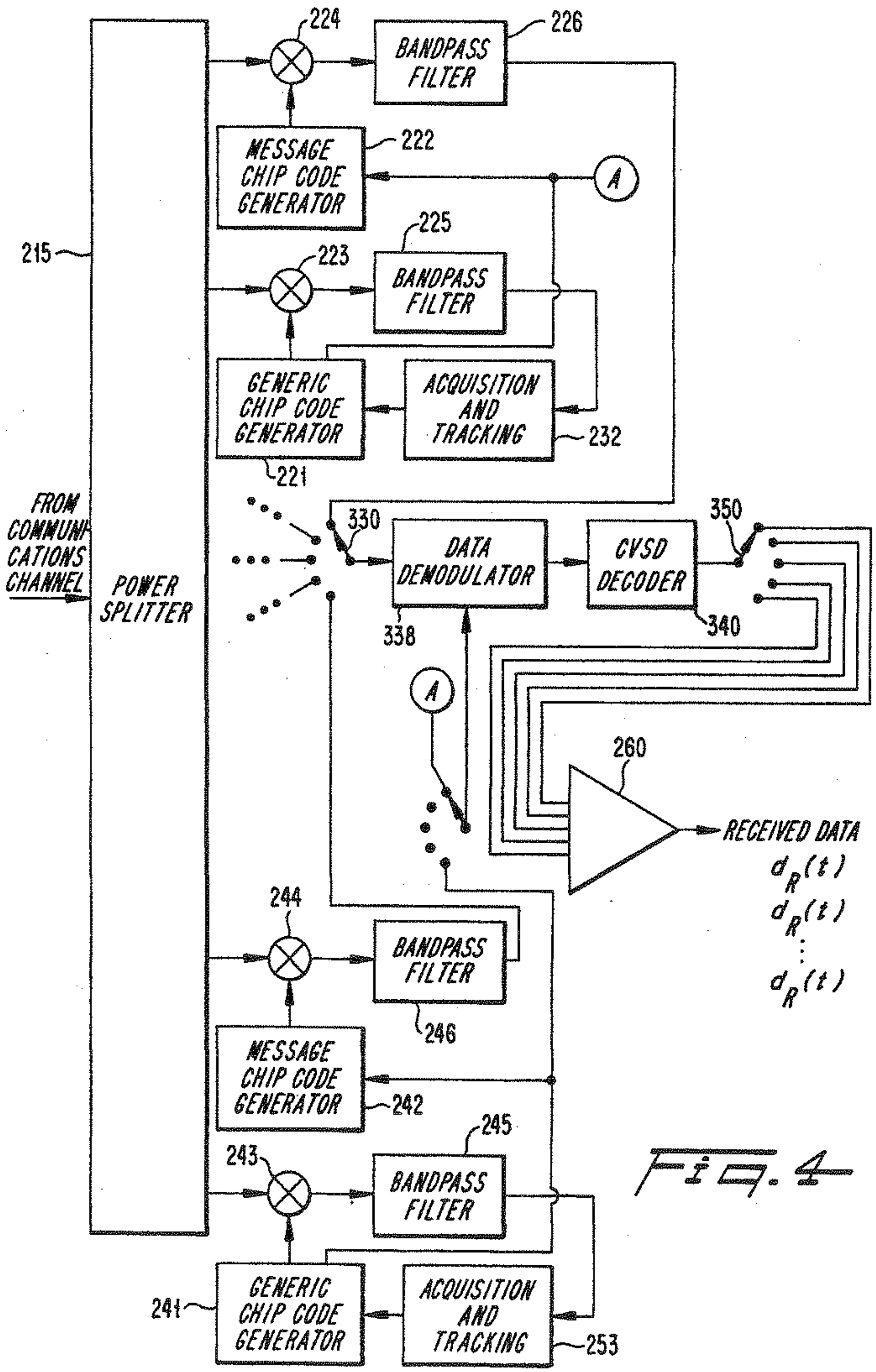
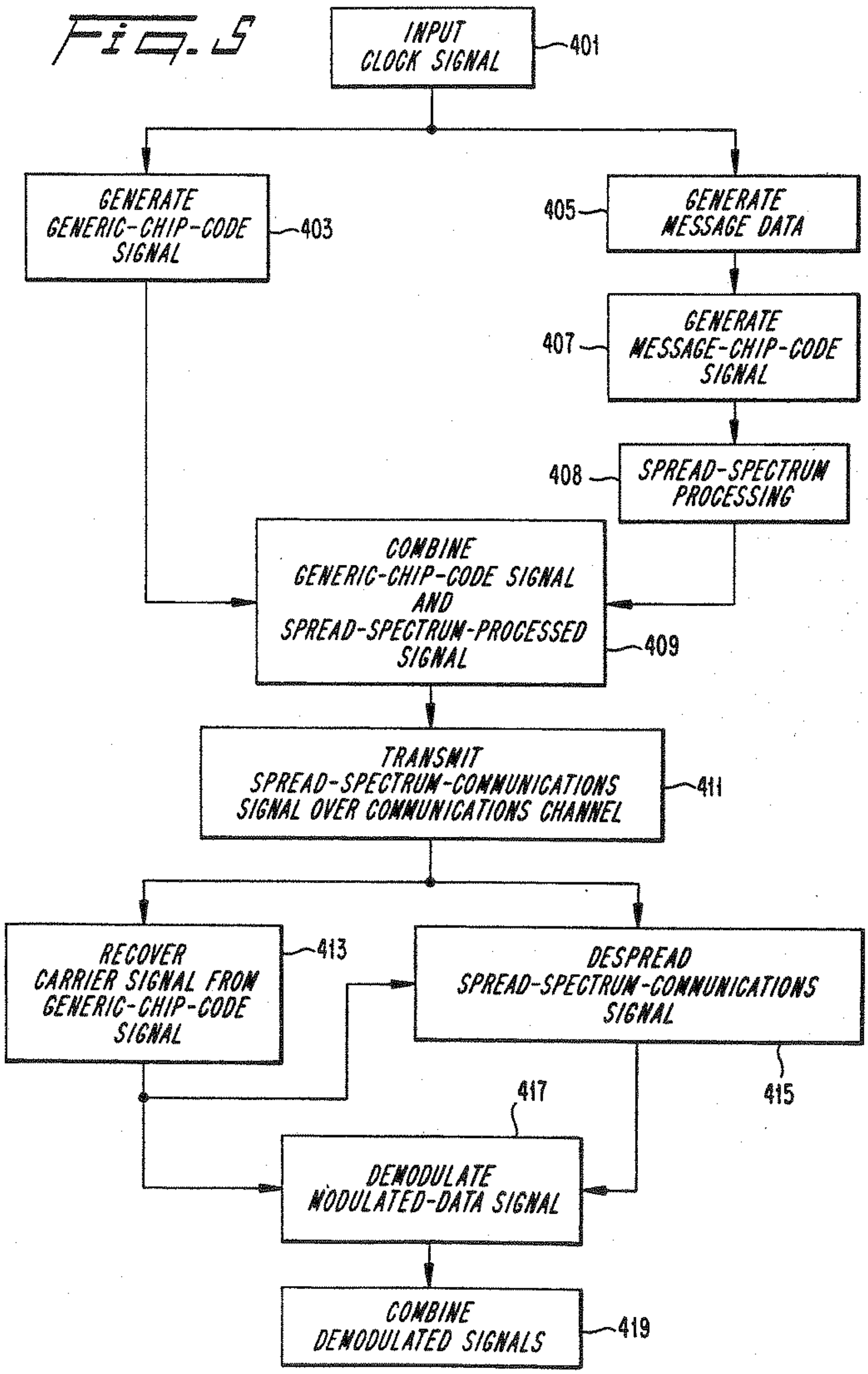

224
226
BANDPASS FILTER
MESSAGE CHIP CODE GENERATOR
222
A
225
223
215
BANDPASS FILTER
GENERIC CHIP CODE GENERATOR
ACQUISITION AND TRACKING
232
221
FROM COMMUNICATIONS CHANNEL
330
350
DATA DEMODULATOR
CVSD DECODER
POWER SPLITTER
338
340
A
260
RECEIVED DATA
$d_R(t)$
$d_R(t)$
$d_R(t)$
244
BANDPASS FILTER
246
MESSAGE CHIP CODE GENERATOR
242
245
243
BANDPASS FILTER
GENERIC CHIP CODE GENERATOR
ACQUISITION AND TRACKING
241
253

FIG. 4

FIG. 5


INPUT CLOCK SIGNAL
401
GENERATE GENERIC-CHIP-CODE SIGNAL
403
405
GENERATE MESSAGE DATA
407
GENERATE MESSAGE-CHIP-CODE SIGNAL
408
SPREAD-SPECTRUM PROCESSING
COMBINE GENERIC-CHIP-CODE SIGNAL AND SPREAD-SPECTRUM-PROCESSED SIGNAL
409
TRANSMIT SPREAD-SPECTRUM-COMMUNICATIONS SIGNAL OVER COMMUNICATIONS CHANNEL
411
RECOVER CARRIER SIGNAL FROM GENERIC-CHIP-CODE SIGNAL
413
DESPREAD SPREAD-SPECTRUM-COMMUNICATIONS SIGNAL
415
417
DEMODULATE MODULATED-DATA SIGNAL
COMBINE DEMODULATED SIGNALS
419

SPREAD SPECTRUM CONFERENCE CALLING SYSTEM AND METHOD

BACKGROUND OF THE INVENTION

This invention relates to spread-spectrum communications and more particularly to a system and method for conference calling with a multiplicity of spread-spectrum signals.

DESCRIPTION OF THE PRIOR ART

Referring to FIG. 1, message data, d(t), are processed by spread-spectrum data modulator **51**, using a message chip code signal, $g_1(t)$, to generate a spread-spectrum data signal. The spread-spectrum data signal is processed by transmitter **52** using a carrier signal at a carrier frequency, f_0, and transmitted over communications channel **53**.

At a receiver, a spread-spectrum demodulator **54** despreads the received spread-spectrum signal, and the message data are recovered by synchronous data demodulator **60** as received-message data. The synchronous data demodulator **60** uses a reference signal for synchronously demodulating the despread spread-spectrum signal. The square-law device **55**, bandpass filter **56** and frequency divider **57** are well known in the art for generating a reference signal from a received modulated data signal. A Costas Loop or other reference signal generating circuit is also adequate.

The spread-spectrum system of FIG. **1** is limited to a single communications channel, and would not work well for receiving a multiplicity of spread-spectrum signals in a fading environment. In a conference calling situation, where a plurality of uses desire to speak to each other, there is a need for an economical method and apparatus for implementing such a system.

Additionally, in a fading channel, such as the ionosphere, a city or any channel containing multipath, or more generally, any channel in which the received signal's amplitude fluctuates with time, synchronous demodulation is not practical since the phase of the incoming signal typically is not the same as the phase of the reference. In such cases differential phase shift keying (DPSK) is employed. With DPSK the received signal is delayed by one symbol and multiplied by the undelayed signal. If the resulting phase is less than $\pm 90°$ a 0-bit is declared, otherwise a 1-bit is declared. Such a system is complex and suffers degradation of about 6 dB at error rates of 10^{-2}.

Thus, a need exists for a conference calling system which works in a fading environment, and which permits communicating using spread spectrum modulation between a plurality of users.

OBJECTS OF THE INVENTION

An object of the invention is a system and method for synchronously demodulating a plurality of modulated-data signals received from a plurality of users and embedded in a received plurality of spread-spectrum-communications signals, which can serve as a conference calling receiver and which performs well whether or not the signal is fading.

Another object of the invention is synchronous, conference-calling, spread-spectrum-communications system.

SUMMARY OF THE INVENTION

According to the present invention, as embodied and broadly described herein, a spread spectrum communications system for use over a communications channel is provided comprising a plurality of spread-spectrum transmitters and a spread-spectrum-conference calling receiver. Each spread-spectrum transmitter includes generic means, message means, summer means, and transmitter means. The generic means generates a generic-chip-code signal. The message means generates a message-chip-code signal. Message data and each message-chip-code signal are synchronized to the generic-chip-code signal, or to a common clock signal. The spreading means spread-spectrum processes the message data with the message-chip-code signal to generate a spread-spectrum-processed signal. The summer means combines the generic-chip-code signal and the spread-spectrum-processed signal.

The combined signal typically is a multi-level signal, with the instantaneous-combined voltage level equal to the sum of the voltage levels of the message-chip-code signal and the generic-chip-code signal. The combined signal need not be an exact linear combination of the voltage levels. The nonlinearity does not necessarily cause a significant degradation in performance, compared with a linear sum. A multi-level signal is a signal with multiple voltage levels.

The transmitter means transmits the combined generic-chip-code signal and spread-spectrum-processed signal, on a carrier signal over the communications channel as a spread-spectrum-communications signal.

The spread-spectrum-conference-calling receiver can be used for simultaneously receiving a plurality of spread-spectrum channels of a plurality of received spread-spectrum-communications signals. The plurality of received spread-spectrum-communications signals may originate from a plurality of spread-spectrum transmitters. Each spread-spectrum transmitter sends a spread-spectrum-communications signal having message data modulated as a spread-spectrum-processed signal, and combined with a respective generic-chip-code signal.

The spread-spectrum-conference-calling receiver includes a plurality of spread-spectrum receivers and combiner means. Each spread-spectrum receiver has generic-spread-spectrum-processing means, acquisition and tracking means, message-spread-spectrum-processing means, and demodulating means.

Each of the generic-spread-spectrum processing means recovers a carrier signal from a respective spread-spectrum channel of a received spread-spectrum-communications signal, and generates a replica of the generic-chip-code signal of the spread-spectrum channel. Each of the acquisition and tracking means acquires and tracks the recovered carrier signal of the respective spread-spectrum channel. The acquisition and tracking means also synchronizes the generic-spread-spectrum-processing means to the respective recovered carrier signal.

Each of the message-spread-spectrum-processing means despreads the spread-spectrum-communications signal of the respective spread-spectrum channel as a modulated-data signal. Each detection means detects the modulated-data signal as a detected signal, respectively. The detection means may be nonsynchronous or synchronous, for converting the modulated-data signal to the detected signal, respectively.

Each bit-synchronous means uses the respective replica of the generic-chip-code signal produced by the respective generic-spread-spectrum-processing means for synchronizing the "integrating and dumping" of the detected signal. The plurality of "integrated and dumped" detected signals from the plurality of spread-spectrum receivers are referred to as a plurality of of demodulated signals from the plurality of bit-synchronous demodulated signals. The combiner means combines the plurality means, of the plurality of spread-spectrum receivers, as received-message data.

A second embodiment of the spread-spectrum-conference calling receiver for simultaneously receiving a plurality of spread-spectrum channels includes a plurality of spread-spectrum receivers, demodulation means, combiner means and switching means. Each of the plurality of spread-spectrum receivers has generic-spread-spectrum-processing means, acquisition and tracking means and message-spread-spectrum-processing means. Each of the generic-spread-spectrum-processing means generates a replica of a generic-chip-code signal. The generic-spread-spectrum-processing means uses the replica of the generic-chip-code signal for recovering a carrier signal from a respective spread-spectrum channel from one of the received spread-spectrum-communications signals. Each acquisition and tracking means acquires and tracks the recovered carrier signal, and synchronizes the generic-spread-spectrum-processing means to the recover carrier signal.

Each of the message-spread-spectrum-processing means despreads the respective spread-spectrum channel of the spread-spectrum-communications signal as a modulated-data signal. Each of the message-spread-spectrum-processing means derives synchronization from a respective replica of the generic-chip-code signal provided by the respective generic-spread-spectrum-processing means.

A single demodulating means is employed for demodulating each modulated-data signal as a respective demodulated signal. The demodulation means includes detection means and bit-synchronous means. The demodulation means is used on a time-shared basis. Accordingly, the detection means sequentially detects each of the plurality of modulation-data signals from the plurality of message-spread-spectrum-processing means, as a detected signal, respectively. The detection means may be synchronous or nonsynchronous for converting each of the plurality of modulated-data signals to a detected signal.

Each of the detected signals is "integrated and dumped" by bit-synchronous means. The bit-synchronous means derives synchronization from a replica of the generic-chip-code signal produced by generic-spread-spectrum-processing means.

Switching means is coupled between an input of the demodulation means and each output of the message-spread-spectrum-processing means. The switching means also is coupled between the output of the demodulation means and a plurality of inputs of the combiner means. The switching means switches the demodulation means between each of the message-spread-spectrum-processing means and each input of the combiner means, respectively. A single demodulation means accordingly demodulates, by time sharing, each of the modulated-data signals as a respective demodulated signal, from each of the message-spread-spectrum-processing means. The combiner means, by time-sharing the demodulation means, combines each of the demodulated signals to generate the received-message data.

The present invention also includes a method for conference calling spread spectrum communications. The method comprises the steps of generating a generic-chip-code signal and a message-chip-code signal. The message data are modulo-2 added to the message-chip-code signal to generate a spread-spectrum-processed signal. The generic-chip-code signal and the spread-spectrum-processed signal are combined and transmitted on a carrier signal over the communications channel as a spread-spectrum-communications signal.

At the receiver, the steps include recovering the carrier signals from a plurality of received spread-spectrum-communications signals, and despreading the plurality of received spread-spectrum communications signal as a plurality of modulated-data signals. Each recovered-carrier signal is used to synchronize a step of generating a replica of the generic-chip-code signal at the transmitter.

A plurality of replicas of the message-chip-code signals is synchronized to the plurality of replicas of the generic-chip-code signals for despreading the plurality of received spread-spectrum-communications signals as a plurality of modulated-data signals, respectively. The plurality of modulated-data signals is detected as a plurality of detected signals, respectively. The recovered-carrier signal optionally may be used to synchronously demodulate the plurality of modulated-data signals as the plurality of detected signals. Each of the detected signals is synchronously converted to a demodulated signal, by using timing from the replica of the generic-chip-code signal to control "integrating and dumping" functions of a lowpass filter and electronic switch. The plurality of demodulated signals is combined to generate the received-message data.

Additional objects and advantages of the invention will be set forth in part in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention. The objects and advantages of the invention also may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate preferred embodiments of the invention, and together with the description serve to explain the principles of the invention.

FIG. 1 is a prior art scheme for synchronously recovering message data;

FIG. 2 shows a synchronous spread-spectrum transmitter;

FIG. 3 shows a spread spectrum receiver for conference call;

FIG. 4 shows a spread spectrum receiver with time multiplexing a data demodulator and decoder for conference call; and

FIG. 5 is a flow chart of the method according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference will now be made in detail to the present preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings,

wherein like reference numerals indicate like elements throughout the several views.

This patent is related to U.S. patent application Ser. No. 07/622,235, filing date Dec. 5, 1990, entitled SPREAD SPECTRUM CDMA COMMUNICATIONS SYSTEM by Donald L. Schilling, and to U.S. patent application Ser. No. 07/626,109, filing date Dec. 14, 1990, entitled SYNCHRONOUS SPREAD-SPECTRUM COMMUNICATIONS SYSTEM AND METHOD, which are both incorporated herein by reference.

The following disclosure first discusses a spread-spectrum transmitter, then the two embodiments of a spread-spectrum-conference-calling receiver. Broadly, this disclosure teaches apparatus and method for conference calling message data, from a plurality of spread-spectrum transmitters.

The spread-spectrum transmitter includes generic means, message means, summer means, and transmitting means. The generic means generates a generic-chip-code signal. The message means generates a message-chip-code signal. Message data and the message-chip-code signal are synchronized to the generic-chip-code signal. The spreading means spread-spectrum processes the message data with the message-chip-code signal to generate a spread-spectrum-processed signal.

The summer means combines the generic-chip-code signal with the spread-spectrum-processed signal. The combined signal typically is a multi-level signal, with the instantaneous-combined voltage level equal to the sum of the voltage levels of the message-chip-code signal and the generic-chip-code signal. A multi-level signal is defined as a signal with multiple voltage levels. The combined signal need not be an exact linear combination of the voltage levels, and the nonlinearity in the sum can be due to a nonlinear amplifier. The nonlinearity does not necessarily cause a significant degradation in performance, compared with a linear sum.

The transmitting means transmits the combined generic-chip-code signal and the spread-spectrum-processed signal, on a carrier signal over the communications channel as a spread-spectrum-communications signal.

Referring to FIG. 2, the message means may be embodied as a transmitter-message-chip-code generator **102**, the spreading means may be embodied as an EXCLUSIVE-OR gate **103**, and the generic means may be embodied as a generic-chip-code generator **101**.

In FIG. 2, the transmitter-message-chip-code generator **102** generates a message-chip-code signal, $g_1(t)$. The generic-chip-code generator **101** generates a generic-chip-code signal, $g_0(t)$. The transmitter-generic chip-code generator **101** preferably is coupled to the transmitter-message-chip-code generator **102** for providing timing to the transmitter-message-chip-code generator **102**. Synchronous timing of the message data, d(t), and the plurality of message-chip code signals, is provided by the generic-chip-code signal, although other sources can be used, such as a common clock signal, for synchronization.

The EXCLUSIVE-OR gate **103** generates a spread-spectrum-processed signal by spread-spectrum processing message data, d(t), with the message-chip-code signal, $g_1(t)$. The spread-spectrum processing may be accomplished by modulo-2 adding the message data, d(t), with the message-chip-code signal, $g_1(t)$. The message-chip-code signal uses a chip codeword to spread-spectrum process the message data.

The combiner **105** combines the generic-chip-code signal and the spread-spectrum-processed signal, by adding the generic-chip-code signal with the spread-spectrum-processed signal. The combined signal typically is a multi-level signal, having the instantaneous voltage levels which are the sum of the voltage levels of the generic-chip-code signal and the spread-spectrum-processed signal.

The modulator **107**, as part of the transmitter, modulates the combined generic-chip-code signal and the spread-spectrum-processed signal by a carrier signal, $\cos w_o t$, at a carrier frequency, f_o. The modulated generic-chip-code signal and the spread-spectrum processed signal are transmitted over the communications channel as a spread-spectrum-communications signal, $x_c(t)$, at a single carrier frequency. The spread-spectrum-communications signal, $x_c(t)$, has the form:

$$x_c(t) = \{g_0(t) + [g_1(t) + d(t)]\} \cos w_o t$$

Thus, the spread-spectrum-communications signal includes the generic-chip-code signal, i.e. a generic-chip codeword, and the spread-spectrum-processed signal as if they were each modulated separately, and synchronously, on separate carrier signals, with each carrier signal having the same carrier frequency, f_o. The spread-spectrum-communication signal is transmitted over the communications channel.

The present invention also provides a method for transmitting spread spectrum. The method includes the steps of generating a generic-chip-code signal; generating a message-chip-code signal and spread-spectrum processing the message data with the message-chip-code signal to generate a spread-spectrum-processed signal. The message data and the message-chip-code signal are synchronized to the generic-chip-code signal, or a common clock signal. The method also includes combining the generic-chip-code signal with the spread-spectrum-processed signal, and transmitting the combined generic-chip-code signal and the spread-spectrum-processed signal on a carrier signal over the communications channel as a spread-spectrum-communications signal.

The spread-spectrum-conference-calling receiver can be used for simultaneously receiving a plurality of spread-spectrum channels of a plurality of received spread-spectrum-communications signals. Each of the received spread-spectrum-communications signals has a spread-spectrum-communications signal. The plurality of received spread-spectrum-communication signals typically originate from a plurality of spread-spectrum transmitters, respectively. Thus, each of the spread-spectrum channels may originate from message data converted to a spread-spectrum-processed signal, from a spread-spectrum transmitter.

A first implementation of the spread-spectrum-conference-calling receiver includes a plurality of spread-spectrum receivers and combiner means. Each of the spread-spectrum receivers includes generic-spread-spectrum-processing means, acquisition and tracking means, message-spread-spectrum-processing means, and demodulation means.

In each of the spread-spectrum receivers the generic-spread-spectrum-processing means recovers a carrier signal from a generic-spread-spectrum channel of a received spread-spectrum-communications signal. The generic-spread-spectrum channel has the generic-chip-code signal which was combined with spread-spectrum-

processed signal at the respective spread-spectrum transmitter. The acquisition and tracking means synchronizes the generic-spread-spectrum-processing means to the recovered carrier signal.

As illustratively shown in FIG. 3, a first generic-spread-spectrum-processing means is embodied as a first receiver-generic-chip-code generator **221**, a first generic mixer **223** and a first generic-bandpass filter **225**, and a first acquisition and tracking means is embodied as a first acquisition and tracking circuit **232**. An N^1 generic-spread-spectrum-processing means is embodied as an N^1 receiver-generic-chip-code generator **241**, an N^1 generic mixer **243**, and an N^{th} generic-bandpass filter **245**, and an N^1 acquisition and tracking means is embodied as an N^1 acquisition and tracking circuit **253**. For each generic-spread-spectrum-processing means shown in FIG. 3, a generic mixer is coupled between a generic-bandpass filter and a receiver-generic-chip-code generator. Each acquisition and tracking circuit is coupled to an output of a generic-bandpass filter and to a generic-chip-code generator, respectively.

With the use of the invention as embodied in FIG. 3, a plurality of generic-spread-spectrum channels, as part of the spread-spectrum-communications signal, provides a plurality of recovered-carrier signals. Looking at the block diagram of the first spread-spectrum receiver of FIG. 3, a first acquisition and tracking circuit **232** acquires and tracks the recovered-carrier signal from an output of the generic-bandpass filter **225**. The replica of the generic-chip-code signal from the receiver-generic-chip-code generator **221** is synchronized to the recovered-carrier signal via acquisition and tracking circuit **232**. The receiver-generic-chip-code generator **221** generates a replica of the generic-chip-code signal, $g_0(t)$, which provides timing to bit synchronizer **229** and to the corresponding receiver-message-chip-code generator **222**.

If the signal out of the generic-bandpass filter is small, then the acquisition and tracking circuit delays the phase of the generic-chip-code signal and the correlation process is repeated. If the phase of the replica of the generic-chip-code signal and the generic-chip-code signal in the spread-spectrum-communications signal are the same, then the output of the generic-bandpass filter will be at a high voltage level.

Each spread-spectrum receiver has message-spread-spectrum-processing means for despreading a spread-spectrum channel of one of the plurality of received spread-spectrum-communications signals, as a modulated-data signal. The message-spread-spectrum processing means derives synchronization from a replica of the generic-chip-code signal, or other synchronization signal, provided by the generic-spread-spectrum-processing means.

The first message-spread-spectrum-processing means of a first spread-spectrum receiver, as shown in FIG. 3, may be embodied as a first receiver message-chip-code generator **222**, a first message mixer **224** and a first message-bandpass filter **226**. The first message mixer **224** is connected between the first message-chip-code generator **222** and the first message-bandpass filter **226**. The N^1 message-spread-spectrum-processing means is illustrated as the N^1 receiver-message-chip-code generator **242**, the N^1 message mixer **244** and the N^1 message-bandpass filter **248**. For each spread-spectrum receiver, a message mixer is coupled between a receiver-message-chip-code generator and a message-bandpass filter, respectively. The plurality of message mixers is coupled to the power splitter **215**.

Each of the message-chip-code generators of a respective spread-spectrum receiver generates a replica of a message-chip-code signal, i.e. the chip codeword used to modulate the message data, for the spread-spectrum channel of the received spread-spectrum-communications signal being received from a respective spread-spectrum transmitter. Thus, a spread-spectrum receiver uses the same chip codeword as used at a respective spread-spectrum transmitter.

For each spread-spectrum receiver, a message mixer mixes a received spread-spectrum-communications signal with the replica of the message-chip-code signal to generate a modulated-data signal. The modulated-data signal is a modulated version of message data on a carrier signal, without spread-spectrum modulation. A message-bandpass filter filters the modulated-data signal.

Each spread-spectrum receiver has demodulation means for demodulating a modulated-data signal as a demodulated signal. The demodulation means includes detection means and bit-synchronous means. The detection means detects the modulated-data signal as a detected signal. The detection means may be synchronous or nonsynchronous, for converting a modulated-data signal to a detected signal. In the illustrative example of FIG. 3, the detection means is embodied as a data detector. More particularly, the first spread-spectrum receiver is shown with a first data detector **228**, which is coupled to the first bandpass filter **226**, and the N^1 spread-spectrum receiver is shown with an N^1 data detector **248**, which is coupled to the N^1 bandpass filter **246**. If a data detector uses synchronous detection, then a recovered-carrier signal from a respective generic-bandpass filter can serve as the reference signal for synchronously detecting the respective message-data signal as a detected signal. If the data detector uses nonsynchronous detection, as encountered with an envelope detector, then the recovered-carrier signal is not required. Each of the plurality of data detectors are coupled to one of the plurality message-bandpass filters, respectively.

The plurality of bit-synchronization means may be embodied as a plurality of bit synchronizers, a plurality of lowpass filters and a plurality of electronic switches, respectively. The plurality of bit synchronizers is shown as first bit synchronizer **229** through N^1 bit synchronizer **249**. The plurality of lowpass filters is shown as first lowpass filter **230**, through N^1 lowpass filter **250**. The plurality of electronic switches is shown as first electronic switch **231**, through N^1 electronic switch **251**.

Each of the plurality of bit synchronizers is coupled to an output of the respective generic-bandpass filter. The recovered-carrier signal from the generic-bandpass filter also serves as the reference signal for synchronously demodulating each of the plurality of modulated-data signals by the plurality of synchronous detectors, as a plurality of demodulated signals, $d_1(t)$, $d_2(t)$, . . . , $d_N(t)$.

Each of the bit synchronizers of the plurality of spread-spectrum receivers uses a replica of the generic-chip-code signal produced by the respective generic-chip-code generator. The generic-chip-code signal synchronizes the "integrating and dumping" of the detected signal. The "integrated and dumped" detected signal is referred to as a demodulated signal.

The plurality of bit synchronizers derive timing from the plurality of replicas of the generic-chip-code signals, and the timing of the integrating and dumping functions of the plurality lowpass filters and the plurality of electronic switches.

The combiner means is shown in FIG. 3 as a combiner 260. The outputs from each of the electronic switches is coupled to an input of a combiner 260. The combiner 260 combines the plurality of demodulated signals as received message data.

A second embodiment of the spread-spectrum-conference-calling receiver for simultaneously receiving a plurality of spread-spectrum channels includes a plurality of spread-spectrum receivers, demodulation means, combiner means and switching means. Each of the plurality of spread-spectrum receivers has generic-spread-spectrum-processing means, acquisition and tracking means and message-spread-spectrum-processing means. Each of the generic-spread-spectrum-processing means generates a replica of the generic-chip-code signal. The generic-spread-spectrum-processing means uses the replica of the generic-chip-code signal for recovering a carrier signal from a respective spread-spectrum channel of a received spread-spectrum-communications signal.

In FIG. 4, first generic-spread-spectrum-processing means, of a first spread-spectrum receiver, is embodied as a first receiver-generic-chip-code generator 221, a first generic mixer 223 and a first generic-bandpass filter 225, and a first acquisition and tracking means is embodied as a first acquisition and tracking circuit 232. An N^{th} generic-spread-spectrum-processing means is embodied as an N^{th} receiver-generic-chip-code generator 241, an N^1 generic mixer 243, and an N^1 generic-bandpass filter 245, and an N^{th} acquisition and tracking means is embodied as an N^{th} acquisition and tracking circuit 253. For each generic-spread-spectrum-processing means embodied in FIG. 3, a generic mixer is coupled between a generic-bandpass filter and a receiver-generic-chip-code generator. Each acquisition and tracking circuit is coupled to an output of a generic-bandpass filter, respectively.

As with the circuits shown in FIG. 3, the plurality of generic-spread-spectrum channels provides a plurality of recovered-carrier signals. Also, if the signal out of the generic-bandpass filter is small, then the acquisition and tracking circuit delays the phase of the generic-chip-code signal and the correlation process is repeated. If the phase of the replica of the generic-chip-code signal and the generic-chip-code signal in the spread-spectrum-communications signal are the same, then the output of the generic-bandpass filter will be at a high voltage level.

The message-spread-spectrum-processing means of each spread-spectrum receiver despreads the respective spread-spectrum channel of the plurality of received spread-spectrum-communications signals as a modulated-data signal. Each message-spread-spectrum-processing means derives synchronization from a replica of the generic-chip-code signal, or other synchronization signal, provided by the generic-spread-spectrum-processing means.

The first message-spread-spectrum-processing means, as shown in FIG. 4, may be embodied as a first receiver-message-chip-code generator 222, a first message mixer 224 and a first message-bandpass filter 226. The first message mixer 224 is connected between the first message-chip-code generator 222 and the first message-bandpass filter 226. The N^{th} message-spread-spectrum-processing means is illustrated as the N^1 receiver-message-chip-code generator 242, the N^1 message mixer 244, and the N^1 message-bandpass filter 248. For each spread-spectrum receiver, a message mixer is connected between a receiver-message-chip-code generator and a message-bandpass filter, respectively. The plurality of message mixers of the plurality of spread-spectrum receivers is connected to the power splitter 215.

The plurality of message mixers generate replicas of the plurality of message-chip-code signals, $g_1(t)$, $g_2(t)$, . . . , $g_n(t)$, which were used by the plurality of spread-spectrum transmitters, respectively. The plurality of message mixers mix the received spread-spectrum-communications signal with the replicas of the plurality of message-chip-code signals to generate the plurality of modulated-data signals, respectively. The plurality of message-bandpass filters filter the plurality of modulated-data signals, respectively.

A single demodulating means is employed for demodulating each modulated-data signal, from a message-bandpass filter, as a respective demodulated signal. Switching means is coupled between an input of the demodulation means and each output of each of the message-spread-spectrum-processing means. The switching means also is coupled between the output of the demodulation means and a plurality of inputs of the combiner means. The switching means switches the demodulation means between each of the message-spread-spectrum-processing means and each input of the combiner means, respectively. A single demodulation means accordingly demodulates, by time sharing, each of the modulated-data signals as a respective demodulated signal, from each of the message-spread-spectrum-processing means. The combiner means, by time-sharing the demodulation means, combines each of the demodulated signals from the demodulation means. If required, the switching means also switches the demodulation means between each of the generic-spread-spectrum-processing means, for appropriate timing and synchronization.

The demodulation means includes detection means and bit-synchronization means. In FIG. 4, the detection means is embodied as a data demodulator 338. The data demodulator 338 may be a nonsynchronous detector such as an envelope detector or square-law detector. Alternatively, the data demodulator 338 may be a synchronous detector, which uses a recovered-carrier signal which is switched from each of the generic-bandpass filters. The bit-synchronization means includes a lowpass filter and an electronic switch, and a bit synchronizer. The lowpass filter and electronic switch are coupled to the bit synchronizer, similar to the first bit-synchronization means shown in FIG. 3. The bit synchronizer preferably is coupled through an input electronic switch, to the plurality of receiver-generic-chip-code generators of the plurality of spread-spectrum receivers. Alternatively, the bit synchronizer may be coupled to an output of the data detector.

The switching means is shown as input-electronic switch 330 and output-electronic switch 350. The input-electronic switch 330 and the output-electronic switch 350 are synchronized to switch the data demodulator 338 between respective message-bandpass filters and inputs to the combiner 225. Synchronization of the input-electronic switch 330 and the output-electronic switch 350 can be provided through a command channel of the received spread-spectrum communications

signal, or self-synchronized between respective channels from the spread-spectrum receivers. Appropriate buffers are included for this synchronization.

The combiner means, by time-sharing the demodulation means, combines each of the demodulated signals from the demodulation means to generate the received-message data. In FIG. 4, the combiner means is embodied as a combiner 225.

In use, a plurality of spread-spectrum transmitters, each similar to the one in FIG. 2, transmits a plurality of message data, $d_1(t), d_2(t), \ldots, d_N(t)$. For the first transmitter, as an example, the transmitter-generic-chip-code generator 101 generates a first generic-chip-code signal, $g_0(t)$, and the transmitter-message-chip-code generator 102 generates a first message-chip-code signal $g_1(t)$. Synchronous timing of the message-chip-code signals is provided by the generic-chip-code signal, although other sources can be used such as a common clock signal for synchronization. The EXCLUSIVE-OR device 103 generates a spread-spectrum signal by spread-spectrum processing the data signal with the message-chip-code signal. The spread-spectrum processing may be accomplished by modulo-2 adding the demultiplexed-data signal to the message-chip-code signal. The combiner 105 combines the generic-chip-code signal with the spread-spectrum-processed signal. The combined generic-chip-code signal and spread-spectrum-processed signal may be a multilevel signal, having the instantaneous voltage levels of the generic-chip-code signal and the spread-spectrum-processed signal.

The modulator 107, as part of the transmitter, modulates the combined generic-chip-code signal and the plurality of spread-spectrum-processed signals by a carrier signal, $\cos w_o t$, at a carrier frequency, f_o. The modulated generic-chip-code signal and spread-spectrum processed signal are transmitted over the communications channel 110 as a first spread-spectrum-communications signal, $x_c(t)$. Thus, the spread-spectrum-communications signal includes the generic-chip-code signal and the spread-spectrum-processed signal as if they were each modulated separately, and synchronously, on separate carrier signals having the same carrier frequency, f_o, and transmitted over the communications channel.

With the use of the invention as embodied in FIGS. 3 and 4, a generic-spread-spectrum channel, as part of each received spread-spectrum-communications signal, provides a recovered-carrier signal. For each spread-spectrum receiver, and as illustrated with the first spread-spectrum receiver, the acquisition and tracking circuit 232 acquires and tracks the recovered-carrier signal from an output of the generic-bandpass filter 225. For the first spread-spectrum receiver, by way of example, the replica of the first generic-chip-code signal from the first receiver-generic-chip-code generator 221 is synchronized to the first recovered-carrier signal via first acquisition and tracking circuit 232. The first receiver-generic-chip-code generator 221 generates a replica of the first generic-chip-code signal, $g_0(t)$, which provides timing to first bit synchronizer 229 and to the first receiver-message-chip-code generator 222.

The first receiver-generic-chip-code generator 221 generates a replica of the first generic-chip-code signal, $g_0(t)$. The first generic mixer 223 uses the replica of the first generic-chip-code signal for despreading the spread-spectrum-communications signal, $x_c(t)$, from the power splitter 115, as a first recovered-carrier signal. The spread-spectrum channel, of the received spread-spectrum-communications signal having the first generic chip-code signal, $g_0(t)\cos w_o t$, generally does not include data so that despreading the received spread-spectrum-communications signal produces the carrier signal, only. The first generic-bandpass filter 225 filters the first recovered-carrier signal at the carrier frequency, or equivalently, at an intermediate frequency (IF). In comparison to a message-bandpass filter which has a bandwidth sufficiently wide for filtering a modulated-data signal, the first generic-bandpass filter 225 can have a very narrow bandwidth for filtering the recovered carrier signal. The very narrow bandwidth of the first generic-bandpass filter 225 assists in extracting the recovered carrier signal from noise.

The first recovered-carrier signal is used to synchronize the step of generating a replica of the first generic chip-code signal. More particularly, a replica of the first generic-chip-code signal is correlated with the received spread-spectrum-communications signal, which has a generic channel defined by the first generic-chip-code signal at a first spread-spectrum transmitter. If the signal out of the first generic-bandpass filter 225 is small, then the acquisition and tracking circuit 232 delays the phase of the replica of the generic-chip-code signal and the correlation process is repeated. If the phases of the replica of the generic-chip-code signal and the generic-chip-code signal in the received spread-spectrum-communications signal are the same, then the output of the first generic-bandpass filter 225 is at a high voltage level.

The first acquisition and tracking circuit 232 acquires and tracks the recovered-carrier signal from an output of the first generic-bandpass filter 225. The replica of the first generic-chip-code signal from the first receiver-generic-chip-code generator 221 is synchronized to the recovered-carrier signal via first acquisition and tracking circuit 232.

The first receiver-message-chip-code generator 222 generates a replica of the first message-chip-code signal, $g_1(t)$. The replica of the first message-chip-code signal, $g_1(t)$, is synchronized to the replica of the first generic-chip-code signal, $g_0(t)$, from the first receiver-generic-chip-code generator 221. Thus, the first receiver-message-chip-code generator 222, via synchronization to the first receiver-generic-chip-code generator 221, has the same synchronization as the transmitter-message-chip-code generator 102 via synchronization to the transmitter-generic-chip-code generator 101. Accordingly, the spread-spectrum communications channel having the generic-chip-code signal provides coherent spread-spectrum demodulation, i.e. coherent bit synchronization, of the spread-spectrum channels with data.

The first message mixer 224 uses the replica of the message-chip-code signal $g_1(t)$, for despreading the received spread-spectrum-communications signal, from the power splitter 115, to generate a first modulated-data signal, $d_{R1}(t)\cos w_o t$. The modulated-data signal effectively is the first message-data signal modulated by the carrier signal. The message-bandpass filter 126 filters the first modulated-data signal at the carrier frequency, or equivalently at an intermediate frequency (IF). Down converters, which convert the modulated-data signal to an IF, optionally may be used without altering the cooperative functions or teachings of the present invention.

More generally, the plurality of message mixers generate replicas of the plurality of message-chip-code

signals, $g_1(t)$, $g_2(t)$, . . . , $g_n(t)$, respectively. The plurality of message mixers mix the plurality of received spread-spectrum-communications signal with the replicas of the plurality of message-chip-code signals to generate the plurality of modulated-data-signals, respectively. The plurality of message-bandpass filters filter the plurality of modulated-data signals, respectively.

Referring to FIG. 3, the first date detector 228 demodulates the modulated-data signal as a detected signal. The detected signal is filtered through first lowpass filter 228, sampled by electronic switch 231 and outputted as a first demodulated signal, $d_{R1}(t)$ The demodulated signal, without errors, is identical to the first message-data signal. The first lowpass filter 230 and first electronic switch 231 operate in an "integrate and dump" function, respectively, under the control of the first bit synchronizer 229.

The first bit synchronizer 229 controls the integrating and dumping of first lowpass filter 230 and first electronic switch 231. The first bit synchronizer 229 preferably derives synchronization using the replica of the first generic-chip-code signal, or other synchronization signal, from the first receiver-generic-chip-code generator 221 as illustrated in FIG. 3. The first bit synchronizer also may derive synchronization from an output of the first date detector 228, as illustrated in FIG. 3, when a generic-chip-code signal is not used.

In a preferred embodiment, the first bit synchronizer 229 receives the replica of the first generic-chip-code signal, $g_0(t)$, from the first receiver-generic-chip-code generator 221. The replica of the first generic-chip-code signal, by way of example, may include a chip codeword having 8250 chips. Assuming that there are eleven bits per chip codeword, then there are 750 chips per bit of data. Since the replica of the generic-chip-code signal provides information to the bit synchronizer 129 as to where the chip codeword begins, the first bit synchronizer 229 thereby knows the timing of the corresponding bits for synchronization.

In FIG. 4, demodulation of each modulated data signal from the plurality of spread-spectrum receivers is performed using data demodulator 338, similar to the data demodulation of FIG. 3, as a time share. The CVSD decoder 340 can be used at the output of the data demodulator 338.

The plurality of demodulated signals of FIGS. 3 and 4 are combined by combiner 225 to generate the received-message data. The received-message data are the message data originally transmitted by the plurality of spread-spectrum transmitters.

The present invention also includes a method for synchronously demodulating a spread-spectrum-communications signal. Message data are input to the spreading means. Referring to FIG. 5, for each spread-spectrum transmitter, the method comprises the steps of generating 403 a generic-chip-code signal. The method further includes generating 405 message data and generating 407 a message-chip-code signal synchronized to the generic-chip-code signal, or other clock signal. Message data are processed 408, using a spread-spectrum modulator, with the message-chip-code signal to generate a spread-spectrum-processed signal. The generic-chip-code signal is combined 409 with the spread-spectrum-processed signal. The method transmits 411 the combined generic-chip-code signal and spread-spectrum-processed signal on a carrier signal over the communications channel as a spread-spectrum-communications signal.

The present invention further includes a method for receiving spread-spectrum conference calls. The receiving method uses a replica of each generic-chip-code signal used by each spread-spectrum transmitter for recovering 413 a carrier signal from each spread-spectrum-communications signal, and acquiring and tracking the recovered-carrier signal. The replica of the generic-chip-code signal is synchronized to the recovered-carrier signal. The method includes generating a replica of the message-chip-code signal synchronized to the replica of the generic-chip-code signal. The replica of the message-chip-code signal is used to despread 415 one of the plurality of the received spread-spectrum-communications signals as a modulated-data signal. The modulated-data signal is demodulated 417 as received data.

The receiving method also may have the demodulating step include synchronously demodulating 415, using the recovered-carrier signal, the modulated-data signal as a detected signal, or nonsynchronously demodulating, using an envelope detector, the modulated-data signal to the demodulated signal. A plurality of demodulated data signals are combined 419 as received-message data.

In use, each of the plurality of spread-spectrum transmitters has a transmitter-generic-chip-code generator generating a generic-chip-code signal. Message data at each spread-spectrum transmitter are spread-spectrum processed by an EXCLUSIVE-OR gate with a message-chip-code signal from the transmitter-message-chip-code generator. The combiner combines the generic-chip-code signal with the spread-spectrum-processed signal. The combined signal may be, for example, a multi-level signal, which is generated by adding the voltage levels of the generic-chip-code signal and the spread-spectrum-processed signal. The transmitter transmits on a carrier signal having a carrier frequency, f_o, the combined generic-chip-code signal and the spread-spectrum-processed signal. The spread-spectrum-communications signal is transmitted through the communications channel.

A plurality of received spread-spectrum-communications signals therefore, are transmitted from a plurality of spread-spectrum transmitters, respectively.

At the receiver, consider operations of the first spread spectrum receiver. The first generic-spread-spectrum-processing means, embodied as the first receiver-generic-chip-code generator 221, the first generic mixer 223 and the first generic-bandpass filter 225, cooperatively operate to recover one of the carrier signals from the received plurality of spread-spectrum-communications signals. The first message-spread-spectrum-processing means, embodied as the first receiver-message-chip-code generator 222, the first message mixer 224 and the first message-bandpass filter 226, cooperatively despread the spread-spectrum-communications signal as the modulated-data signal. The first receiver-message-chip-code generator 222 preferably is synchronized to the replica of the generic-chip-code signal or other clock signal from the receiver-generic-chip-code generator 121. The first demodulation means, embodied as the first data detector 228, demodulates the modulated-data signal as received data.

The received data are integrated and dumped by lowpass filter 236 and electronic switch 231, under control of the bit synchronizer 229. The bit synchronizer 229 preferably uses the replica of the generic-chip-

code signal for synchronizing the integrate and dump functions.

The combiner combines the plurality of received data from the plurality of spread-spectrum receivers, as the output message data.

It will be apparent to those skilled in the art that various modifications can be made to the spread spectrum conference calling system and method of the instant invention without departing from the scope or spirit of the invention, and it is intended that the present invention cover modifications and variations of the spread spectrum conference calling system and method provided they come in the scope of the appended claims and their equivalents.

I claim:

1. A spread-spectrum-conference-calling receiver for simultaneously listening to a plurality of spread-spectrum channels of a plurality of received spread-spectrum-communications signals comprising:

combiner means;

a plurality of spread-spectrum receivers, each of said spread-spectrum receivers including,

generic-spread-spectrum-processing means for generating a replica of a generic-chip-code signal for recovering a carrier signal for a respective spread-spectrum channel, from the plurality of received spread-spectrum-communications signals;

acquisition and tracking means responsive to acquiring and tracking the recovered carrier signal for synchronizing said generic-spread-spectrum-processing means to the recovered carrier signal;

message-spread-spectrum-processing means for despreading the spread-spectrum-communications signal as a modulated-data signal; and

demodulation means for demodulating the modulated-data signal as a demodulated signal; and

wherein said combiner means combines each of the plurality of demodulated signals from said plurality of spread-spectrum receivers.

2. The spread-spectrum-conference-calling receiver as set forth in claim 1 wherein:

each of said generic-spread-spectrum-processing means includes a generic mixer for recovering the carrier signal for the respective spread-spectrum channel, from the plurality of received spread-spectrum-communications signals;

each of said message-spread-spectrum-processing means includes a message mixer for despreading the respective spread-spectrum channel from the plurality of received spread-spectrum-communications signals, as the modulated-data signal; and

each of said demodulation means includes an envelope detector for detecting the respective modulated-data signal as the respective demodulated signal.

3. The spread-spectrum conference-calling receiver as set forth in claim I wherein:

each of said generic-spread-spectrum-processing means includes a generic mixer for recovering the carrier signal for the respective spread-spectrum channel, from the plurality of received spread-spectrum-communications signals;

each of said message-spread-spectrum-processing means includes a message mixer for despreading the respective spread-spectrum channel from the plurality of received spread-spectrum-communications signals, as the modulated-data signal; and

demodulation means includes a synchronous detector responsive to the recovered-carrier signal for converting the respective modulated-data signal to the respective demodulated signal.

4. A spread-spectrum-conference-calling receiver for simultaneously listening to a plurality of spread-spectrum channels of a plurality of received spread-spectrum-communications signals comprising:

a plurality of spread-spectrum receivers, each of said spread-spectrum receivers including generic-spread-spectrum-processing means for generating a replica of a generic-chip-code signal for recovering a carrier signal for a respective spread-spectrum channel from the plurality of received spread-spectrum-communications signals, acquisition and tracking means responsive to acquiring and tracking the recovered carrier signal for synchronizing said generic-spread-spectrum-processing means to the recovered carrier signal, and message-spread-spectrum-processing means for despreading a respective spread-spectrum channel of the plurality of received spread-spectrum-communications signals as a modulated-data signal;

demodulation means for demodulating the modulated-data signal as a demodulated signal;

combiner means having a plurality of inputs for combining a plurality of demodulated signals; and

switching means coupled between an input of said demodulation means and each of said message-spread-spectrum-processing means and between an output of said demodulation means and the plurality of inputs of said combiner means, for switching said demodulation means between each of said message-spread-spectrum-processing means and each input of said combiner means, respectively.

5. The spread-spectrum-conference-calling receiver as set forth in claim 4 wherein:

each of said generic-spread-spectrum processing means includes a generic mixer for recovering the carrier signal for the respective spread-spectrum channel, from the plurality of received spread-spectrum-communications signals;

each of said message-spread-spectrum-processing means includes a message mixer for despreading the respective spread-spectrum channel from the plurality of received spread-spectrum-communications signals, as the modulated-data signal; and

said demodulation means includes an envelope detector for detecting the respective modulated-data signal as the respective demodulated signal.

6. The spread-spectrum-conference-calling receiver as set forth in claim 4 wherein:

each of said generic-spread-spectrum-processing means includes a generic mixer for recovering the carrier signal for the respective spread-spectrum channel, from the plurality of received spread-spectrum-communications signals;

each of said message-spread-spectrum-processing means includes a message mixer for despreading the respective spread-spectrum channel from the plurality of received spread-spectrum-communications signals, as the modulated-data signal; and

said demodulation means includes a synchronous detector responsive to the recovered-carrier signal for converting the respective modulated-data signal to the respective demodulated signal.

7. A spread-spectrum-conference-calling receiver for simultaneously listening to a plurality of spread-spec-

trum channels of a plurality of received spread-spectrum-communications signals comprising:

a combiner;

a plurality of spread-spectrum receivers, each of said spread-spectrum receivers including,

a receiver generic-chip-code generator for generating a replica of a generic-chip-code signal;

a generic mixer coupled to said generic-chip-code generator and responsive to the replica of the generic-chip-code signal for recovering a carrier signal from a respective spread-spectrum channel, from the plurality of received spread-spectrum-communications signals;

an acquisition and tracking circuit coupled to said generic mixer and responsive to acquiring and tracking the recovered carrier signal, for synchronizing said generic-chip-code generator to the recovered carrier signal;

a receiver-message-chip-code generator for generating a message-chip-code signal;

a message mixer coupled to said message-chip-code generator and responsive to the message-chip-code signal for despreading a respective spread-spectrum channel of the plurality of received spread-spectrum-communications signals as a modulated-data signal;

demodulation means for demodulating the modulated-data signal as a demodulated signal; and

wherein said combiner combines each of the plurality of demodulated signals from said plurality of spread-spectrum receivers.

8. The spread-spectrum-conference-calling receiver as set forth in claim 7 wherein each of said demodulation means includes an envelope detector for detecting the respective modulated-data signal as the respective demodulated signal.

9. The spread-spectrum-conference-calling receiver as set forth in claim 7 wherein demodulation means includes a synchronous detector responsive to the recovered-carrier signal for converting the respective modulated-data signal to the respective demodulated signal.

10. A spread-spectrum-conference-calling receiver for simultaneously listening to a plurality of spread-spectrum channels of a plurality of received spread-spectrum-communications signals comprising:

a plurality of spread-spectrum receivers, each of said spread-spectrum receivers including,

a receiver-generic-chip-code generator for generating a replica of a generic-chip-code signal;

a generic mixer coupled to said generic-chip-code generator and responsive to the generic-chip-code signal for recovering a carrier signal for a respective spread-spectrum channel from the spread-spectrum-communications signal;

an acquisition and tracking circuit responsive to acquiring and tracking the recovered carrier signal for synchronizing said generic-chip-code generator means to the recovered carrier signal; and

a receiver-message-chip-code generator for generating a message-chip-code signal;

a message mixer coupled to said message-chip-code generator and responsive to the message-chip-code signal for despreading the spread-spectrum-communications signal as a modulated-data signal;

demodulation means for demodulating the modulated-data signal as a demodulated signal;

a receiver-combiner having a plurality of inputs for combining a plurality of the demodulated signals; and

a switching circuit coupled between an input of said demodulation means and each of said message mixers of said plurality of spread-spectrum receivers, and between an output of said demodulation means and the plurality of inputs of said combiner, for switching said demodulation means between each of said message mixers and each input of said combiner, respectively.

11. The spread-spectrum-conference-calling receiver as set forth in claim 10 wherein said demodulation means includes an envelope detector for detecting the respective modulated-data signal as the respective demodulated signal.

12. The spread-spectrum-conference-calling receiver as set forth in claim 10 wherein said demodulation means includes a synchronous detector responsive to the recovered-carrier signal for converting the respective modulated-data signal to the respective demodulated signal.

13. A method for simultaneously listening to a plurality of spread-spectrum channels of a plurality of received spread-spectrum communications signals, comprising the steps for each spread-spectrum channel of:

generating a replica of a generic-chip-code signal for a respective spread-spectrum channel;

recovering, using the replica of the respective generic-chip-code signal, a respective carrier signal from the plurality of received spread-spectrum-communications signals;

acquiring and tracking the recovered-carrier signal and synchronizing the replica of the generic-chip-code signal to the recovered-carrier signal;

generating a replica of the message-chip-code signal synchronized to the replica of the generic-chip-code signal;

despreading, using the replica of the message-chip-code signal, the spread-spectrum channel of the spread-spectrum-communications signal as a modulated-data signal; and

demodulating the modulated-data signal as a demodulated signal.

14. The method as set forth in claim 13 wherein the demodulating step includes synchronously demodulating, using the recovered-carrier signal, the respective modulated-data signal as a respective demodulated signal.

15. The spread spectrum communications system as set forth in claim 13 wherein the demodulating step includes demodulating, using an envelope detector, the respective modulated-data signal as the respective demodulated signal.

* * * * *

US006075792A

United States Patent [19]

Ozluturk

[11] Patent Number: 6,075,792

[45] Date of Patent: Jun. 13, 2000

[54] CDMA COMMUNICATION SYSTEM WHICH SELECTIVELY ALLOCATES BANDWIDTH UPON DEMAND

[75] Inventor: Fatih M. Ozluturk, Port Washington, N.Y.

[73] Assignee: InterDigital Technology Corporation, Wilmington, Del.

[21] Appl. No.: 08/898,537

[22] Filed: Jul. 22, 1997

Related U.S. Application Data

[60] Provisional application No. 60/049,637, Jun. 16, 1997.

[51] Int. Cl.[7] H04B 7/216

[52] U.S. Cl. 370/441; 370/335; 370/342; 370/524

[58] Field of Search 370/252, 253, 370/328, 329, 335, 342, 441, 479; 375/200; 455/422, 455, 522, 524

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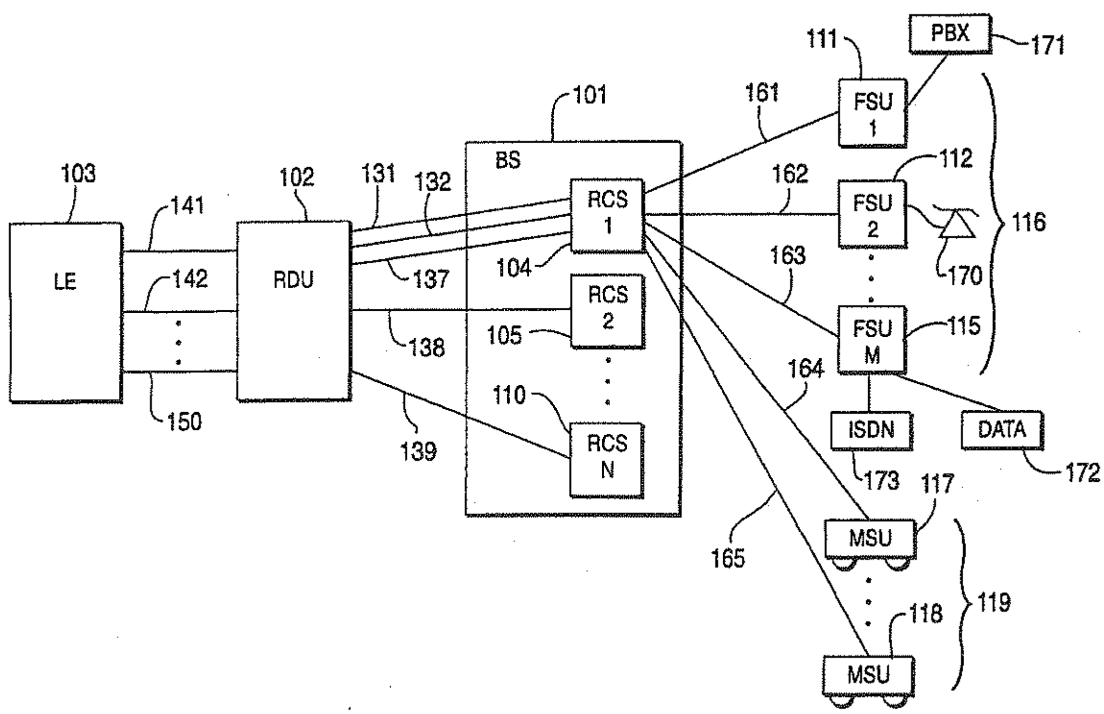
9709810 3/1997 WIPO H04L 23/00

Primary Examiner—Ajit Patel
Assistant Examiner—Bob A. Phunkulh
Attorney, Agent, or Firm—Volpe and Koening, P.C.

[57] ABSTRACT

A CDMA wireless digital communication system which supports all types of voice and data communications while utilizing the minimum amount of bandwidth for the particular application. The system efficiently allocates ISDN bandwidth on demand by a subscriber. Upon initialization of the subscriber unit, the system establishes a channel and generates the necessary spreading codes to support the highest capacity channel desired by the subscriber unit. Portions of the communication spectrum bandwidth are not reserved until actually required by the subscriber unit. Since the call setup is performed at the beginning of a call from that subscriber unit, including the assignment of spreading codes, a subscriber unit can quickly gain access to the portion of the spectrum that is required to support the particular application.

18 Claims, 12 Drawing Sheets



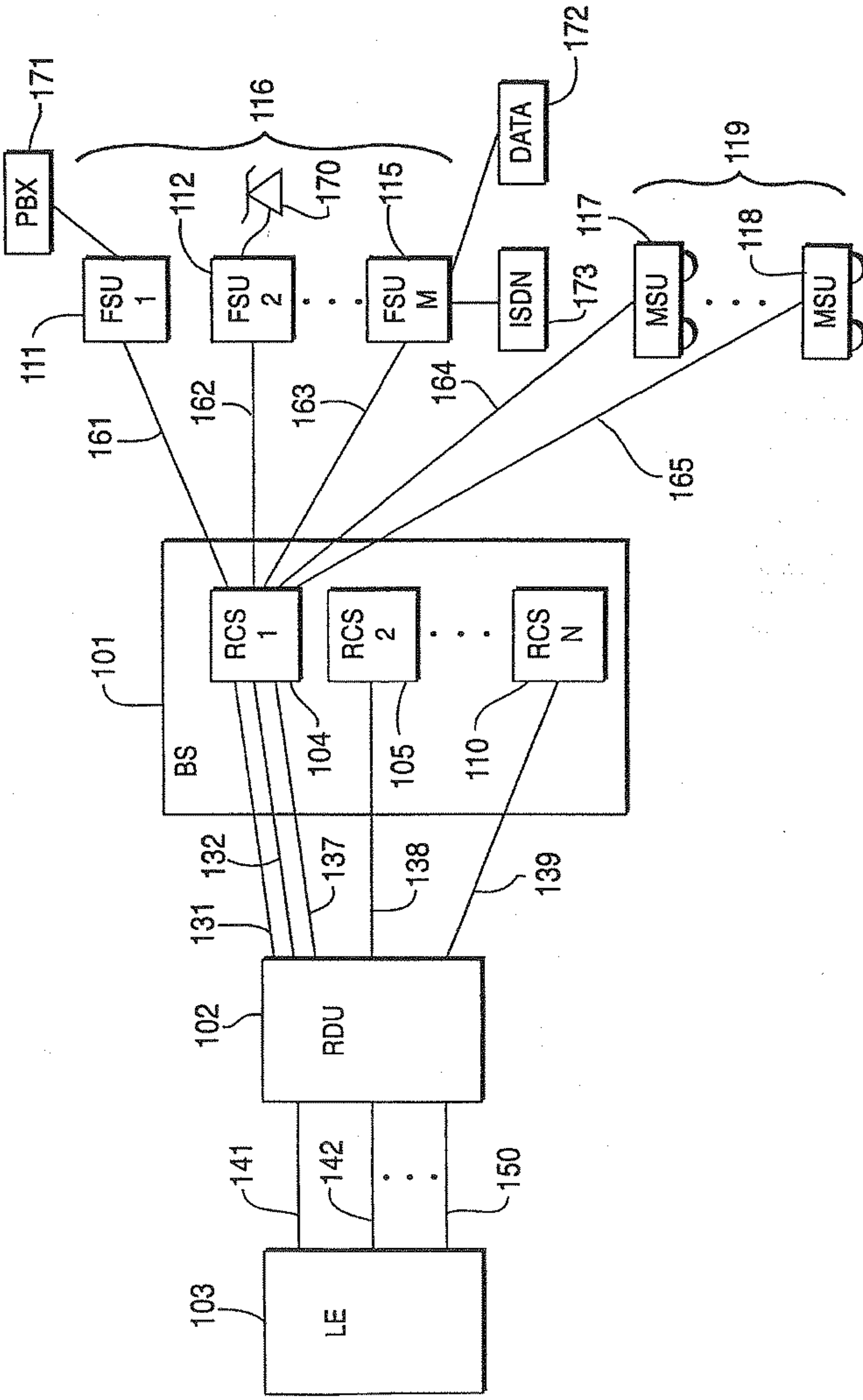
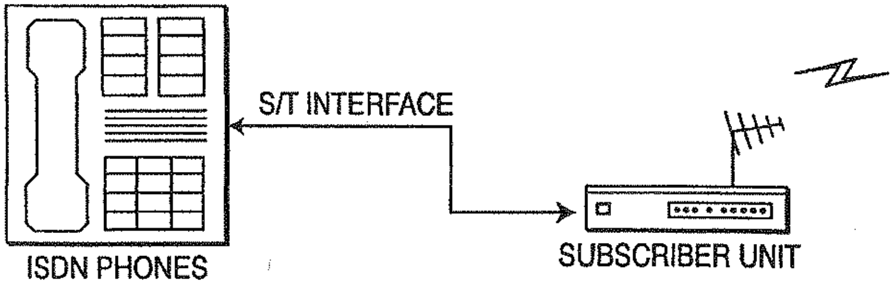
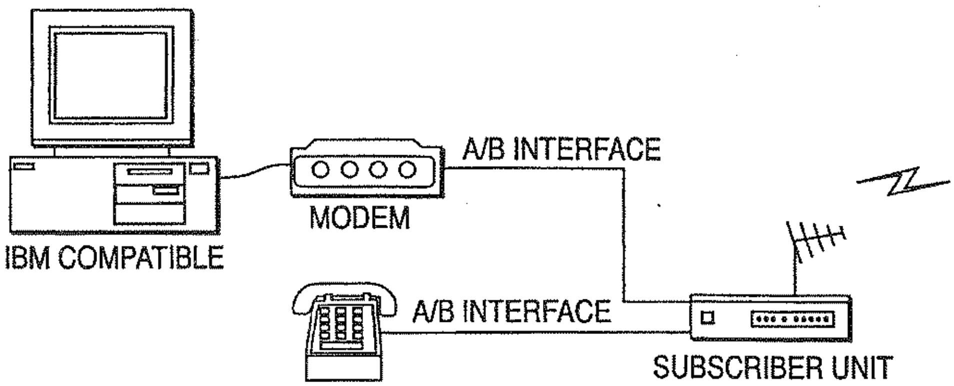

PBX
171
116
DATA
172
FSU 1
FSU 2
FSU M
112
170
115
ISDN
173
MSU
MSU
117
118
119
111
161
162
163
164
165
BS
RCS 1
RCS 2
RCS N
101
104
105
110
131
132
137
138
139
RDU
102
LE
103
141
142
150

FIG. 1



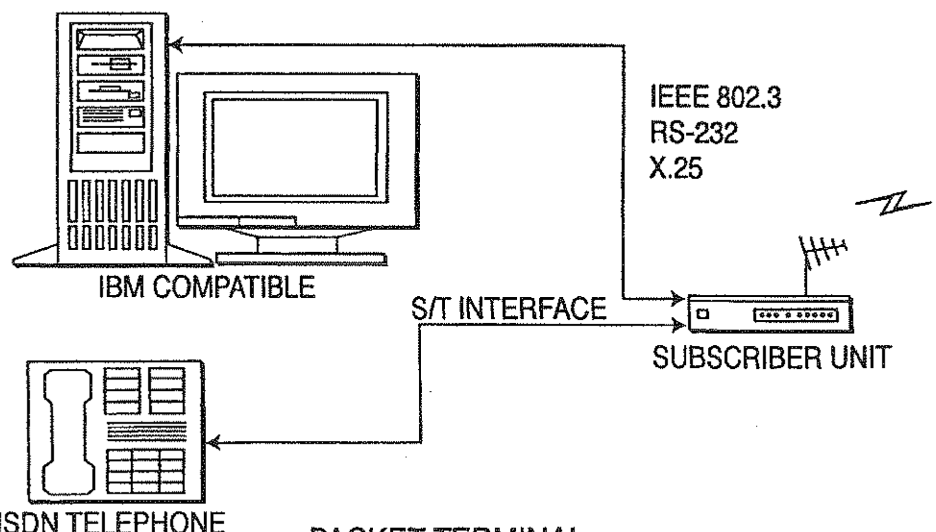
ISDN TERMINAL INTERFACE

FIG. 2A



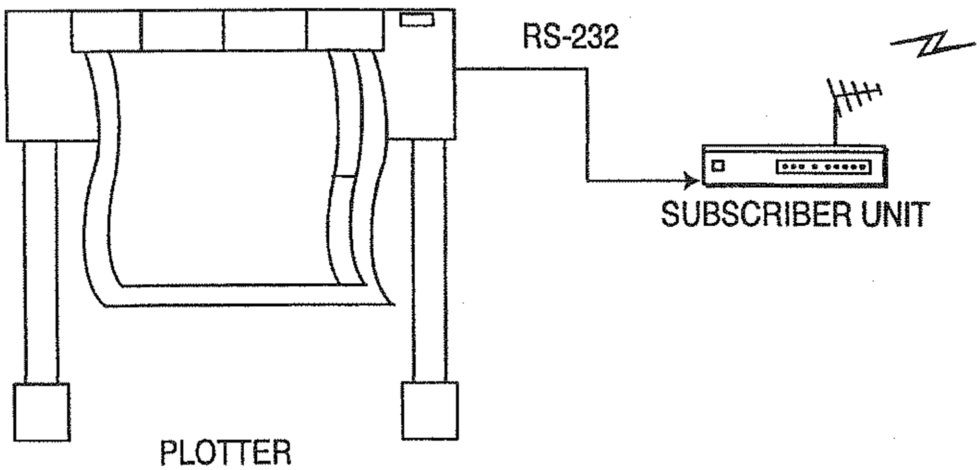
POTS TERMINAL INTERFACE

FIG. 2B

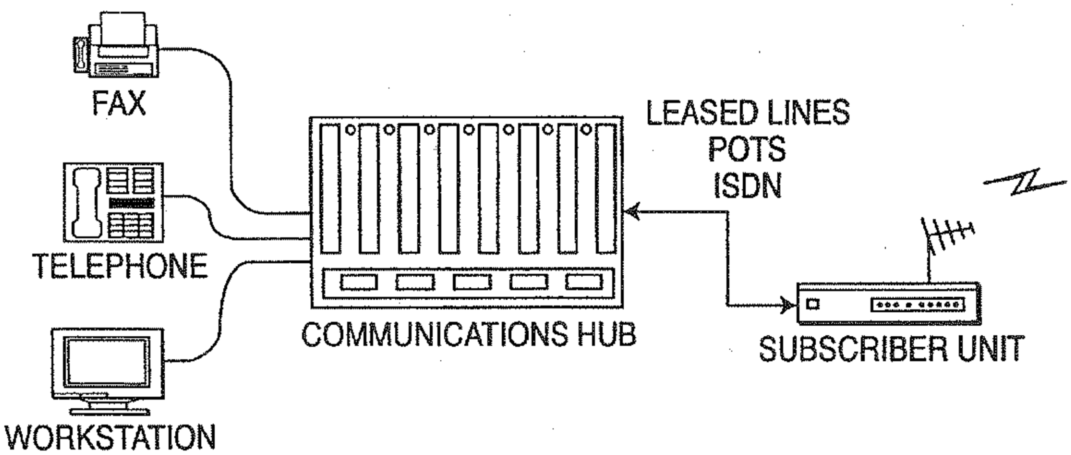


PACKET TERMINAL

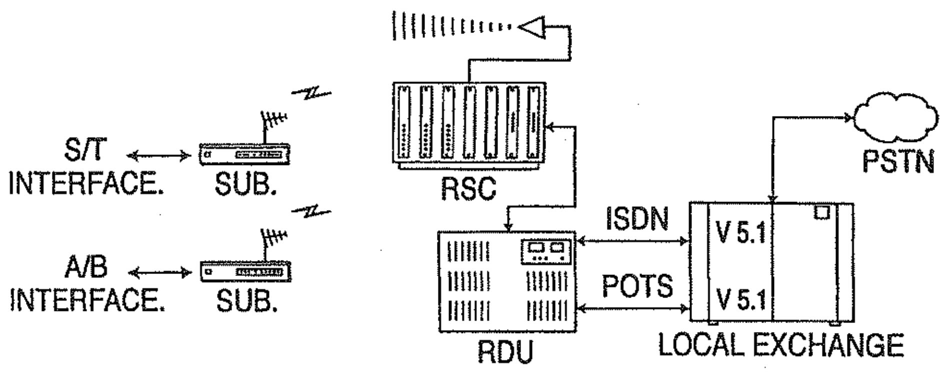
FIG. 2C



WIDEBAND CONNECTION
FIG. 2D

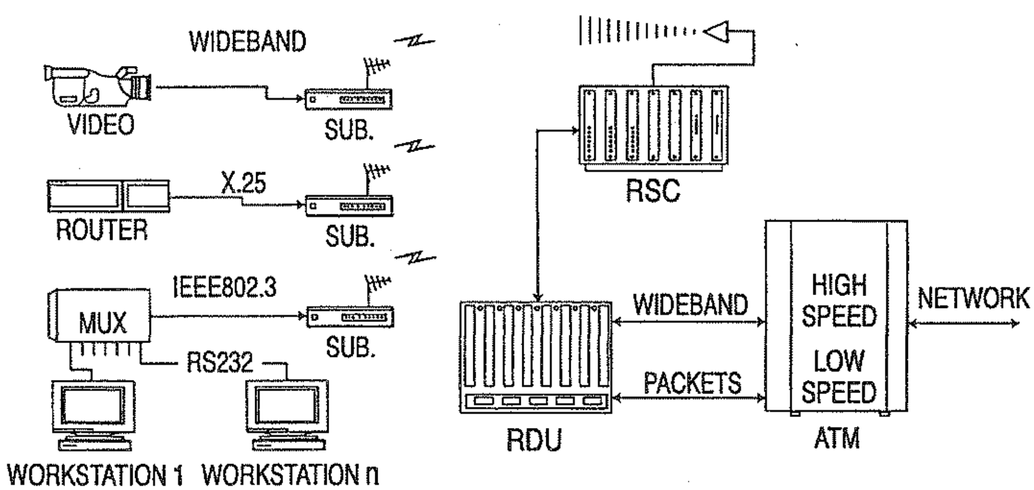


LEASED LINE TERMINAL INTERFACES
FIG. 2E



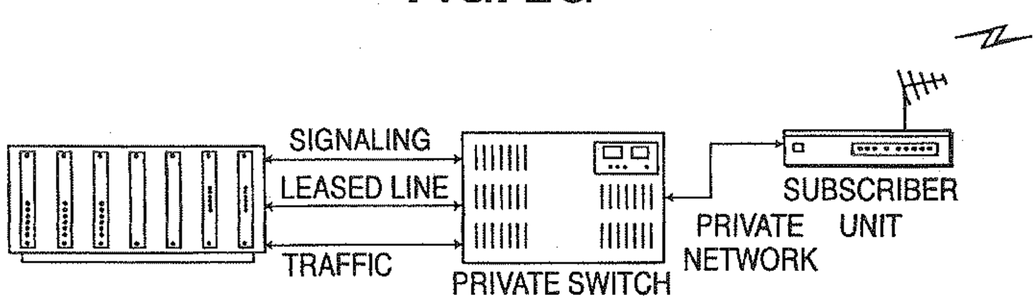
ISDN AND POTS NETWORK INTERFACE

FIG. 2F



WIDEBAND AND PACKET NETWORK INTERFACE

FIG. 2G



LEASED LINE NETWORK INTERFACE

FIG. 2H

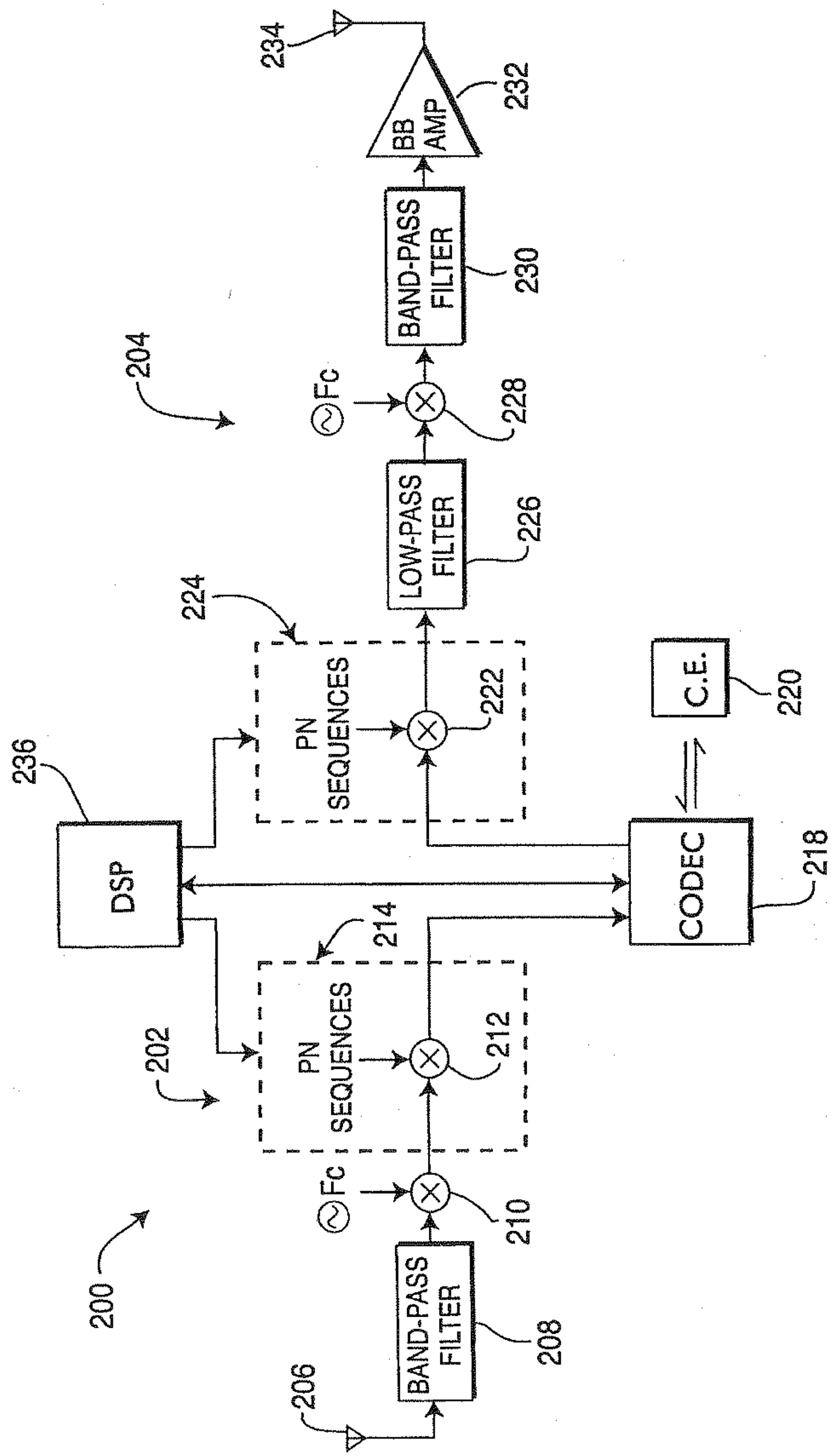

200
202
204
206
BAND-PASS FILTER
208
Fc
210
PN SEQUENCES
212
214
DSP
236
CODEC
218
C.E.
220
PN SEQUENCES
222
224
LOW-PASS FILTER
226
Fc
228
BAND-PASS FILTER
230
BB AMP
232
234

FIG. 3

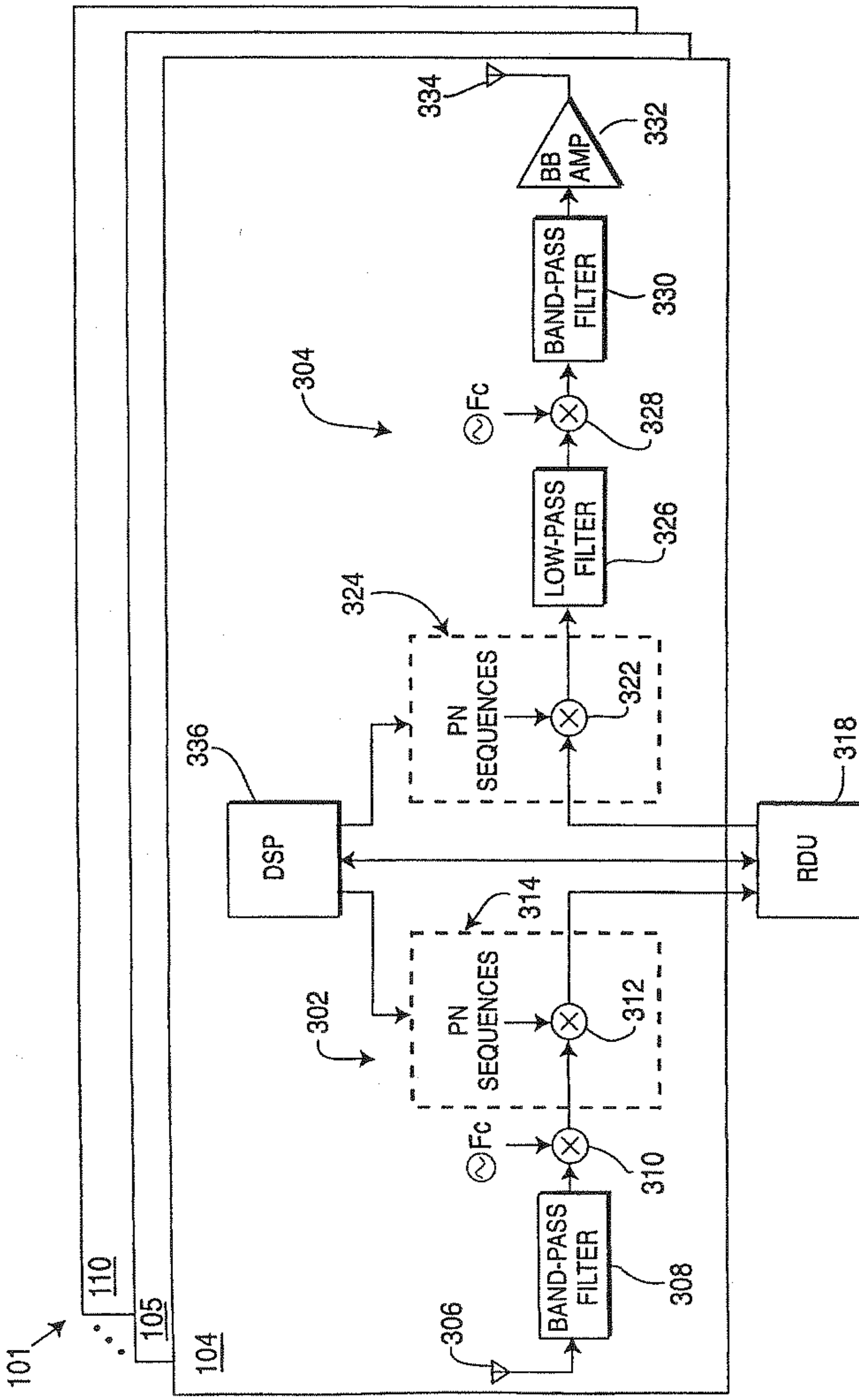

101
110
105
104
306
BAND-PASS FILTER
308
Fc
310
302
PN SEQUENCES
312
314
DSP
336
RDU
318
PN SEQUENCES
322
324
LOW-PASS FILTER
326
Fc
328
304
BAND-PASS FILTER
330
BB AMP
332
334

FIG. 4

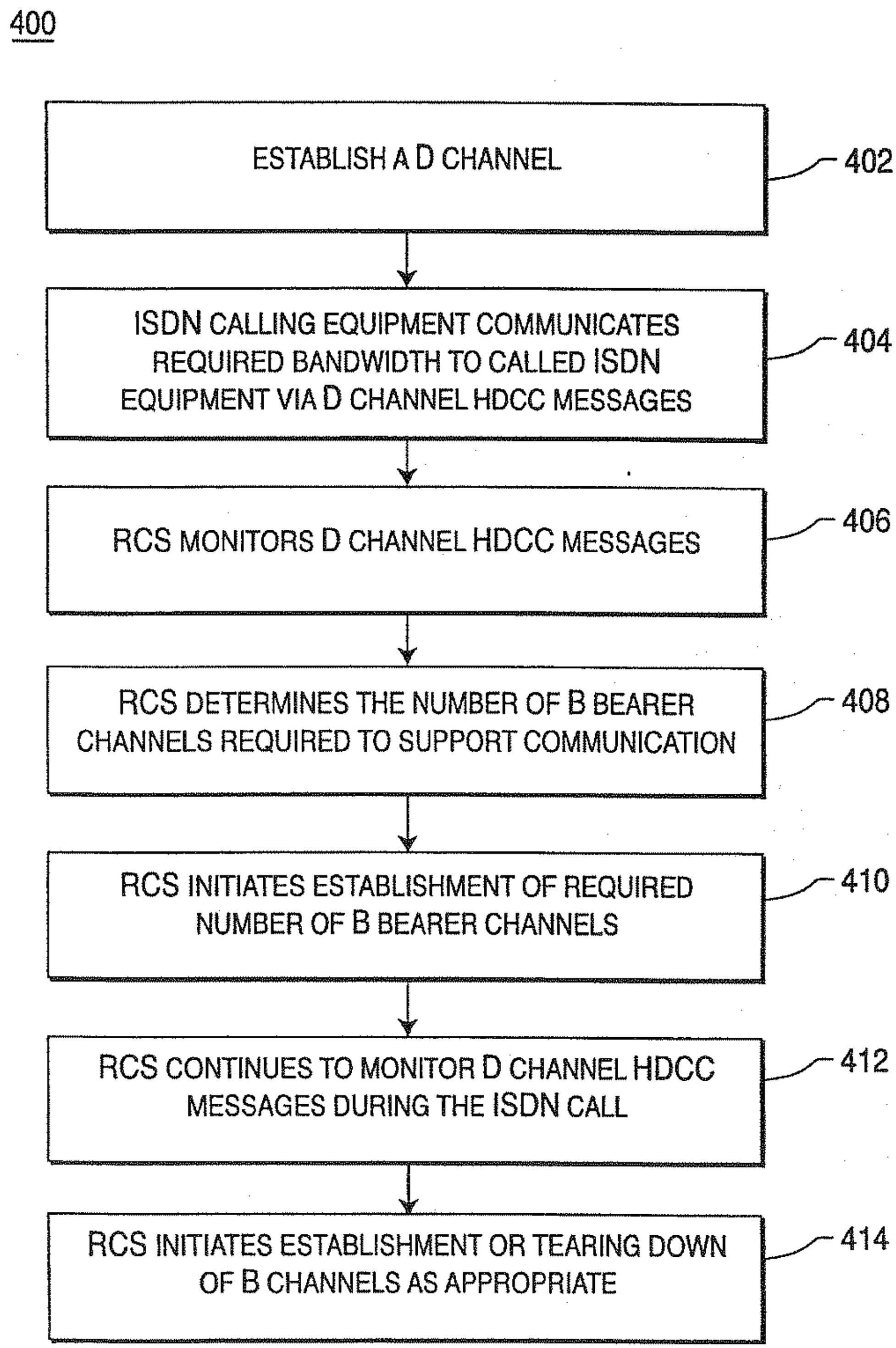

400
ESTABLISH A D CHANNEL
402
ISDN CALLING EQUIPMENT COMMUNICATES REQUIRED BANDWIDTH TO CALLED ISDN EQUIPMENT VIA D CHANNEL HDCC MESSAGES
404
RCS MONITORS D CHANNEL HDCC MESSAGES
406
RCS DETERMINES THE NUMBER OF B BEARER CHANNELS REQUIRED TO SUPPORT COMMUNICATION
408
RCS INITIATES ESTABLISHMENT OF REQUIRED NUMBER OF B BEARER CHANNELS
410
RCS CONTINUES TO MONITOR D CHANNEL HDCC MESSAGES DURING THE ISDN CALL
412
RCS INITIATES ESTABLISHMENT OR TEARING DOWN OF B CHANNELS AS APPROPRIATE
414

FIG. 5

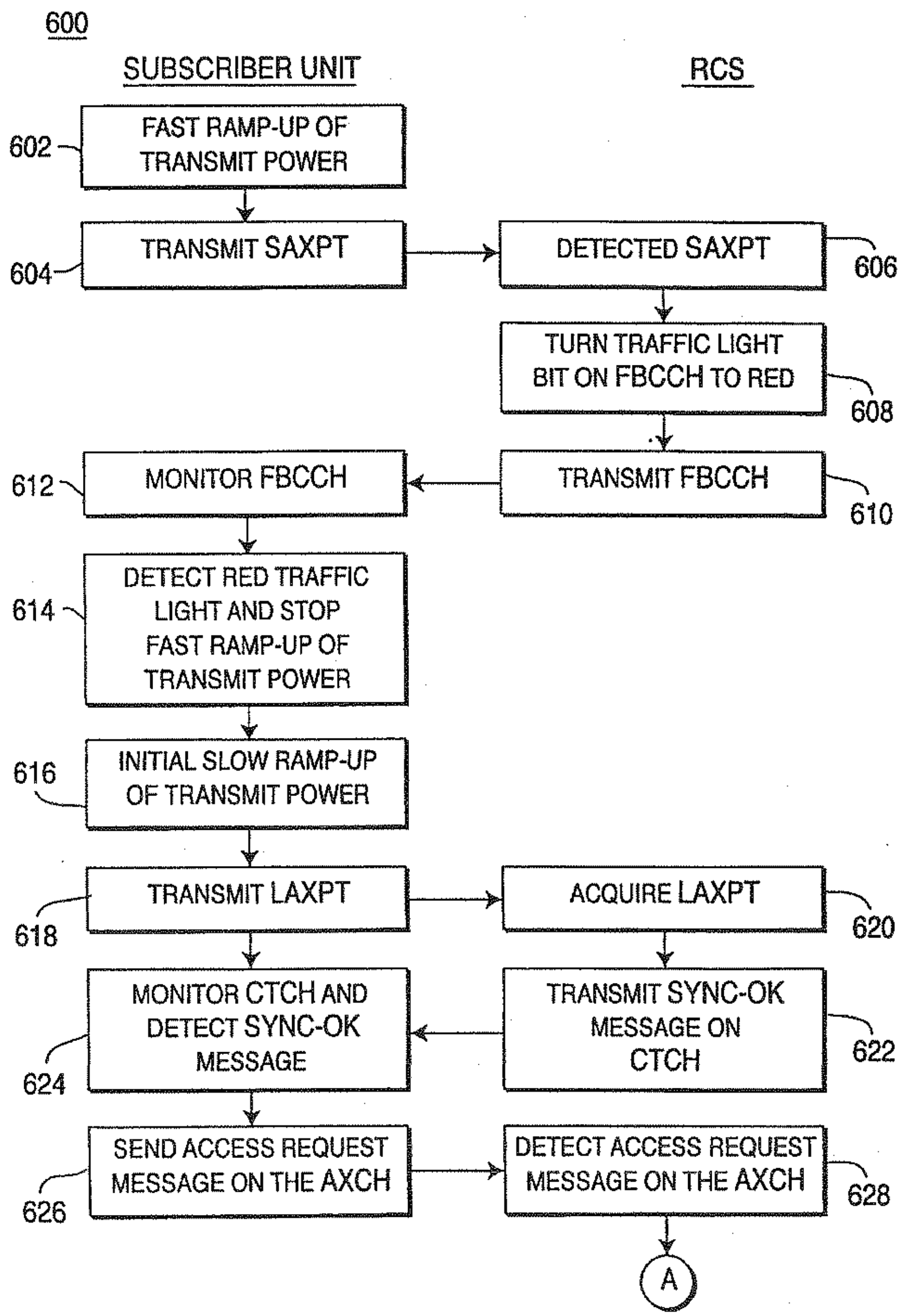
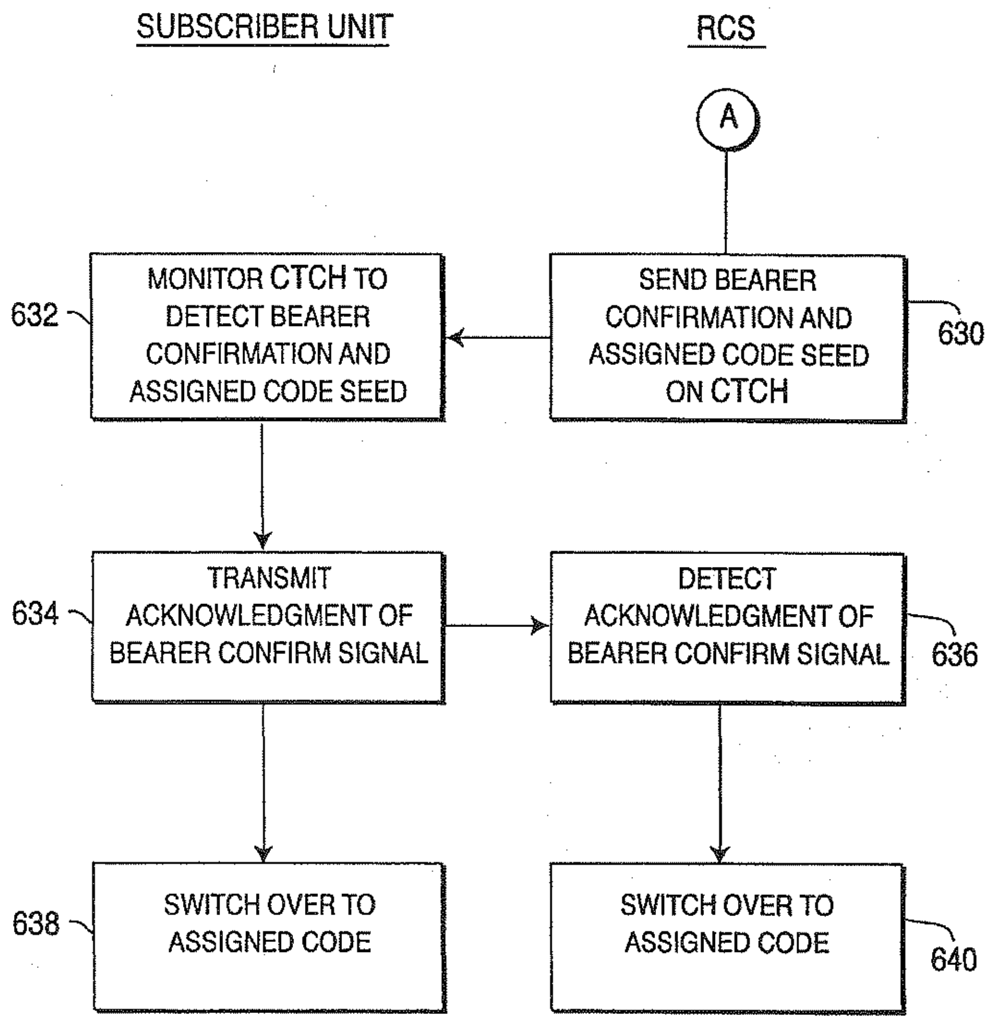

600
SUBSCRIBER UNIT
RCS
FAST RAMP-UP OF TRANSMIT POWER
602
TRANSMIT SAXPT
604
DETECTED SAXPT
606
TURN TRAFFIC LIGHT BIT ON FBCCH TO RED
608
TRANSMIT FBCCH
610
MONITOR FBCCH
612
DETECT RED TRAFFIC LIGHT AND STOP FAST RAMP-UP OF TRANSMIT POWER
614
INITIAL SLOW RAMP-UP OF TRANSMIT POWER
616
TRANSMIT LAXPT
618
ACQUIRE LAXPT
620
TRANSMIT SYNC-OK MESSAGE ON CTCH
622
MONITOR CTCH AND DETECT SYNC-OK MESSAGE
624
SEND ACCESS REQUEST MESSAGE ON THE AXCH
626
DETECT ACCESS REQUEST MESSAGE ON THE AXCH
628
A

FIG. 6A



SUBSCRIBER UNIT
RCS
A
MONITOR CTCH TO DETECT BEARER CONFIRMATION AND ASSIGNED CODE SEED
632
SEND BEARER CONFIRMATION AND ASSIGNED CODE SEED ON CTCH
630
TRANSMIT ACKNOWLEDGMENT OF BEARER CONFIRM SIGNAL
634
DETECT ACKNOWLEDGMENT OF BEARER CONFIRM SIGNAL
636
SWITCH OVER TO ASSIGNED CODE
638
SWITCH OVER TO ASSIGNED CODE
640

FIG. 6B

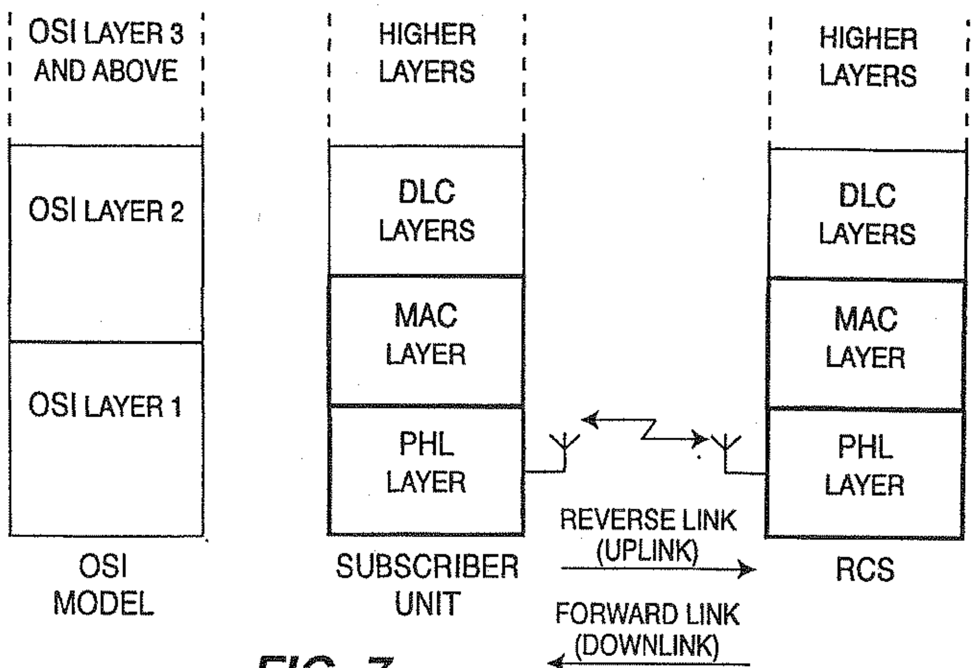


FIG. 7

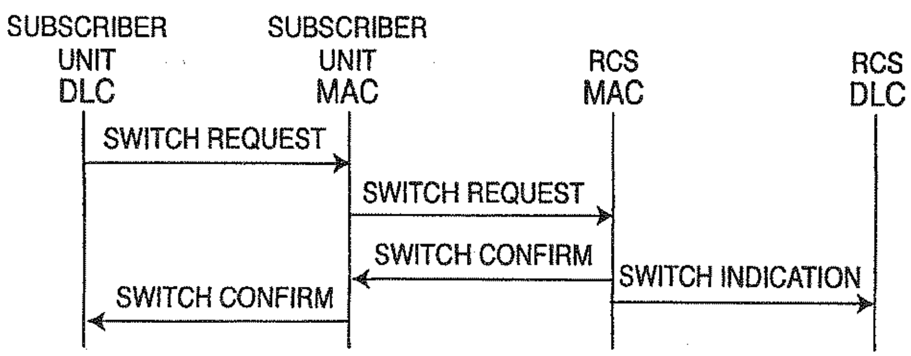


FIG. 8A

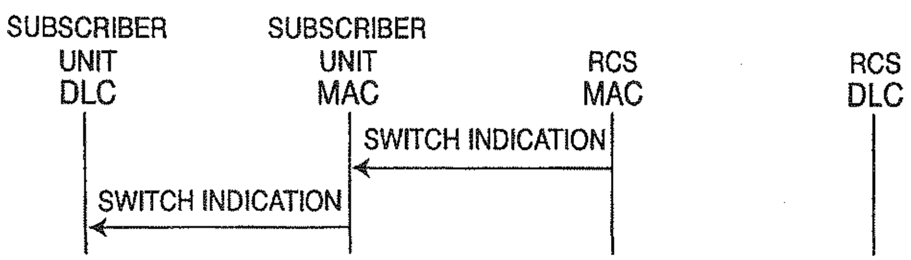


FIG. 8B

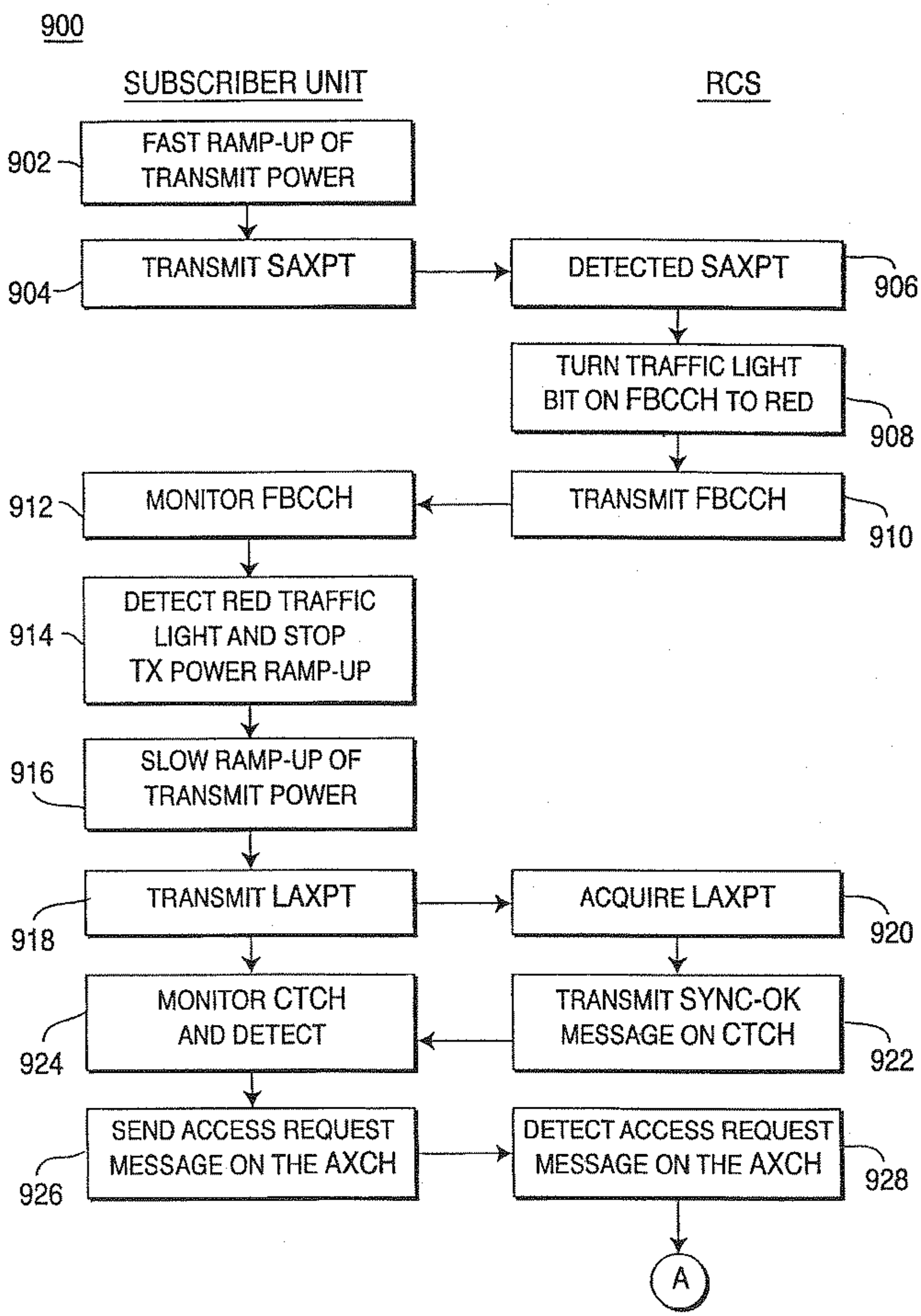

900
SUBSCRIBER UNIT
RCS
902
FAST RAMP-UP OF TRANSMIT POWER
904
TRANSMIT SAXPT
DETECTED SAXPT
906
TURN TRAFFIC LIGHT BIT ON FBCCH TO RED
908
912
MONITOR FBCCH
TRANSMIT FBCCH
910
914
DETECT RED TRAFFIC LIGHT AND STOP TX POWER RAMP-UP
916
SLOW RAMP-UP OF TRANSMIT POWER
918
TRANSMIT LAXPT
ACQUIRE LAXPT
920
924
MONITOR CTCH AND DETECT
TRANSMIT SYNC-OK MESSAGE ON CTCH
922
926
SEND ACCESS REQUEST MESSAGE ON THE AXCH
DETECT ACCESS REQUEST MESSAGE ON THE AXCH
928
A

FIG. 9A

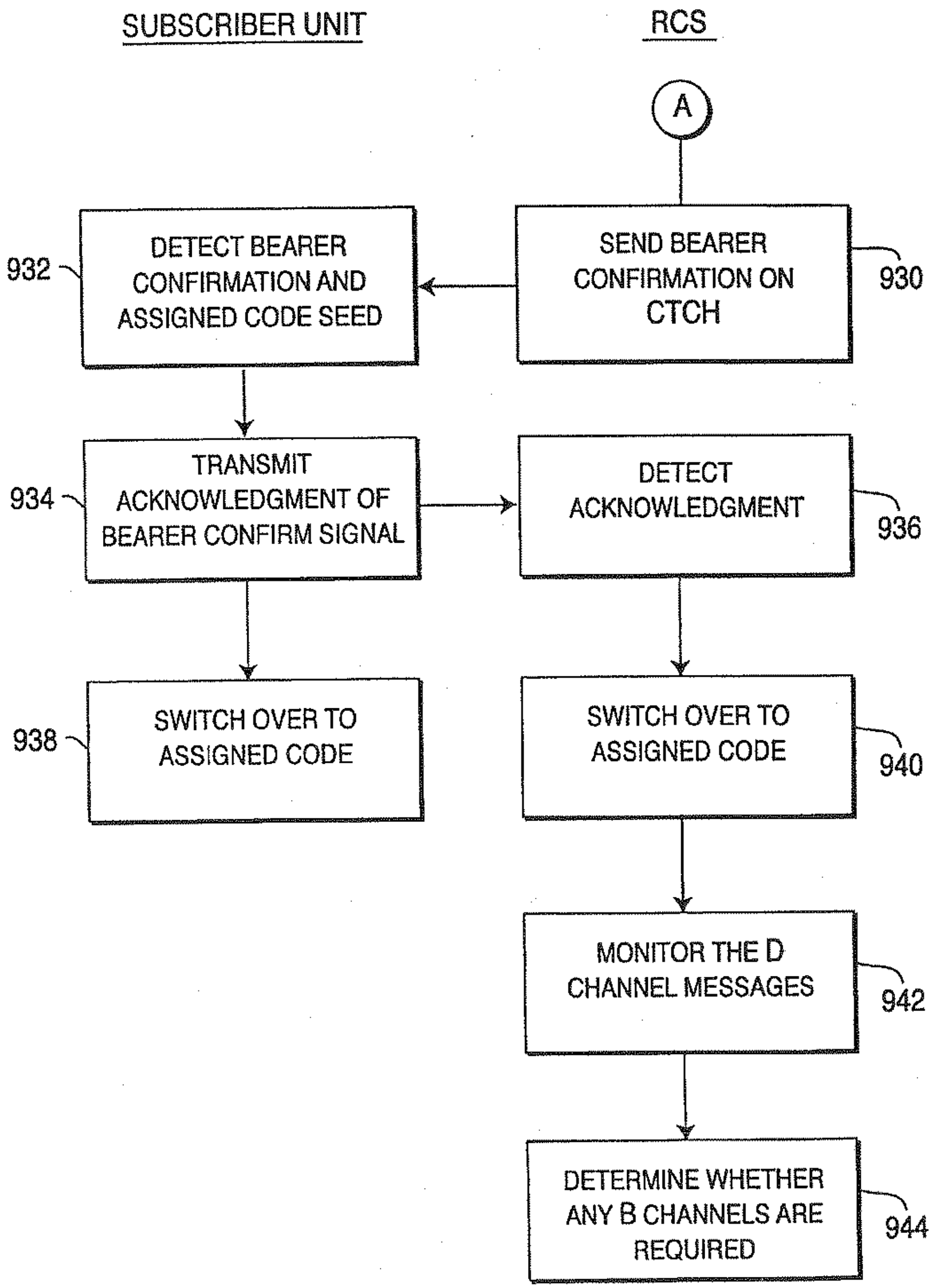

SUBSCRIBER UNIT
RCS
A
DETECT BEARER CONFIRMATION AND ASSIGNED CODE SEED
932
SEND BEARER CONFIRMATION ON CTCH
930
TRANSMIT ACKNOWLEDGMENT OF BEARER CONFIRM SIGNAL
934
DETECT ACKNOWLEDGMENT
936
SWITCH OVER TO ASSIGNED CODE
938
SWITCH OVER TO ASSIGNED CODE
940
MONITOR THE D CHANNEL MESSAGES
942
DETERMINE WHETHER ANY B CHANNELS ARE REQUIRED
944

FIG. 9B

CDMA COMMUNICATION SYSTEM WHICH SELECTIVELY ALLOCATES BANDWIDTH UPON DEMAND

CROSS REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of Provisional Application No. 60/049,637, filed Jun. 16, 1997.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention generally relates to wireless communication systems. More particularly, the invention relates to a wireless digital Code Division Multiple Access (CDMA) communication system including a base station and a plurality of subscriber units which selectively allocates bandwidth upon demand by a subscriber unit or an entity desiring to establish a communication with a subscriber unit.

2. Description of the Related Art

The use of wireless technology by the telecommunication industry has increased dramatically as the capacity and reliability of wireless communication systems has improved. Once considered only to be a convenient method for sending voiced communications, digital wireless communications systems are now a necessity for providing transmission of all forms of communications including plain old telephony service (POTS), integrated services digital network (ISDN), variable bit rate (VBR) data service, wideband service, leased line service and packet data services. Although it has been technically feasible to transmit all of these types of services, the large amount of bandwidth required for high data rate communications has made many of these services uneconomical. As the number of subscribers requiring access to wireless digital communication systems has increased, the reliance on a wide bandwidth for each communication is no longer realistic.

The finite bandwidth allocated to wireless communications systems for public use has become increasingly valuable. Since it is unlikely that additional bandwidth to support user growth will be allocated for existing applications, many of the recent advances in telecommunication hardware and software have been directed toward increasing the transmission rate of data while utilizing a decreased amount of bandwidth.

Accordingly, there exists a need for a wireless digital communication system which supports the same high data rate services as conventional wired networks while utilizing the allocated bandwidth more efficiently.

SUMMARY OF THE INVENTION

The present invention is a CDMA wireless digital communication system which supports all types of voice and data communications while utilizing the minimum amount of bandwidth for the particular application. The system efficiently allocates ISDN bandwidth on demand by a subscriber. Upon initialization of the subscriber unit, the system establishes a channel and generates the necessary spreading codes to support the highest capacity channel desired by the subscriber unit. However, the system does not set aside portions of the communication bandwidth until actually required by the subscriber unit. Since the call setup is performed at the beginning of any call from that particular subscriber unit, including the assignment of spreading codes, a subscriber unit can quickly gain access to the portion of the spectrum that is required to support the particular application.

Accordingly, it is an object of the invention to provide a wireless digital spread spectrum communication system which supports a range of telephone services including POTS and ISDN while efficiently utilizing the spread spectrum bandwidth.

Other objects and advantages of the present invention will become apparent after reading the description of a presently preferred embodiment.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a code division multiple access spread spectrum communication system according to the present invention;

FIG. 2A is a block diagram of the interface between the subscriber unit of the present invention and an ISDN terminal;

FIG. 2B is a block diagram of the interface between the subscriber unit of the present invention and a POTS terminal;

FIG. 2C is a block diagram of the interface between the subscriber unit of the present invention and a packet terminal;

FIG. 2D is a block diagram of the interface between the subscriber unit of the present invention and a wideband connection;

FIG. 2E is a block diagram of the interface between the subscriber unit of the present invention and a leased line terminal;

FIG. 2F is a block diagram of the interface between the subscriber unit of the present invention and an ISDN and POTS network;

FIG. 2G is a block diagram of the interface between the subscriber unit of the present invention and a wideband and packet network;

FIG. 2H is a block diagram of the interface between the subscriber unit of the present invention and a leased line network;

FIG. 3 is a block diagram of a subscriber unit in accordance with the present invention;

FIG. 4 is a block diagram of an RCS in accordance with the present invention;

FIG. 5 is a flow diagram of the procedure for dynamic allocation of bandwidth for ISDN service;

FIGS. 6A and 6B are flow diagrams of the establishment of the bearer channel between the subscriber unit and the RCS for POTS service;

FIG. 7 shows the layered protocol of the communications between the subscriber unit and RCS;

FIG. 8A illustrates the simplified bearer switching method as initiated by the subscriber unit;

FIG. 8B illustrates the simplified bearer switching method as initiated by the RCS; and

FIGS. 9A and 9B are flow diagrams of the establishment of the bearer channel between the subscriber unit and the RCS for ISDN service.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The preferred embodiment will be described with reference to the drawing figures wherein like numerals represent like elements throughout.

The system of the present invention provides local-loop telephone service using radio links between one or more

base stations and at least one remote subscriber unit. In the exemplary embodiment, the radio link is described for a base station communicating with a fixed subscriber unit (FSU), but the system is equally applicable to systems including multiple base stations with radio links to both fixed subscriber units and mobile subscriber units (MSUs). Consequently, the fixed and mobile subscriber units will be referred to herein as subscriber units.

Referring to FIG. **1**, a base station **101** provides call connection to a local exchange **103** or any other telephone network switching interface, such as a private branch exchange (PBX), and includes at least one radio carrier station (RCS) **104**, **105** . . . **110**. One or more RCSs **104**, **105**, **110** connect to a radio distribution unit (RDU) **102** through links **131**, **132**, **137**, **138**, **139** and RDU **102** interfaces with the local exchange **103** by transmitting and receiving call set-up, control, and information signal through telco links **141**, **142**, **150**. The subscriber units **116**, **119** communicate with the RCS **104** through radio links **161**, **162**, **163**, **164**, **165**. Alternatively, another embodiment of the invention includes several subscriber units and a "master subscriber unit" with functionality similar to the RCS **104**. Such an embodiment may or may not have connection to a local telephone network.

The radio links **161** to **165** operate within the frequency bands of the CDS1800 standard (1.71–1.785 GHz and 1.805–1.880 GHZ); the US-PCS standard (1.85–1.99 GHz); and the CEPT standard (2.0–2.7 GHz). Although these bands are used in the described embodiment, the invention is equally applicable to any RF frequency band including the entire UHF and SHF bands, and bands from 2.7 GHZ to 5 GHz. The transmit and receive bandwidths are multiples of 3.5 MHz starting at 7 MHz, and multiples of 5 MHz starting at 10 MHz, respectively. The described system includes bandwidths of 7, 10, 10.5, 14 and 15 MHz. In the exemplary embodiment of the invention, the minimum guard band between the uplink and downlink is 20 MHz, and is desirably at least three times the signal bandwidth. The duplex separation is between 50 to 175 MHz, with the described invention using 50, 75, 80, 95 and 175 MHz. Other frequencies may also be used.

Although the system may use different spread-spectrum bandwidths centered around a carrier for the transmit and receive spread-spectrum channels, the present invention is readily extended to systems using multiple spread-spectrum bandwidths for the transmit channels and multiple spread-spectrum bandwidths for the receive channels. Alternatively, the same spread-spectrum bandwidth for both the transmit and receive channels may be employed wherein uplink and downlink transmissions will occupy the same frequency band. The present invention may also be readily extended to multiple CDMA frequency bands, each conveying a respectively different set of messages, uplink, downlink or uplink and downlink.

The spread binary symbol information is transmitted over the radio links **161** to **165** using quadrature phase shift keying (QPSK) modulation with Nyquist pulse shaping. However, other modulation techniques may be used including, but not limited to, offset QPSK minimum shift keying (MSK), Gaussian phase shift keying (GPSK) and M-ary phase shift keying (MPSK).

The radio links **161** to **165** incorporate broadband code division multiple access (B-CDMA™) technology as the mode of transmission in both the uplink and downlink directions. CDMA (also known as spread spectrum) communication techniques used in multiple access systems are well-known, and are described in U.S. Pat. No. 5,228,056 entitled SYNCHRONOUS SPREAD-SPECTRUM COMMUNICATION SYSTEM AND METHOD by Donald Schilling. The system described utilizes the direct sequence spreading technique. The CDMA modulator generates the spread-spectrum spreading code sequence, which can be a pseudonoise sequence, and performs complex direct sequence modulation of the QPSK signals with spreading code sequences for the In-phase (I) and Quadrature (Q) channels. Pilot signals, spreading codes which are not modulated by data, are generated and transmitted with the modulated signals. The pilot signals are used for synchronization, carrier phase recovery, and for estimating the impulse response of the radio channel. Each subscriber unit **111–118** includes a code generator and at least one CDMA modulator and demodulator, which together comprise a CDMA modem. Each RCS **104**, **105**, **110** has at least one code generator plus sufficient CDMA modulators and demodulators for all of the logical channels in use by the subscriber units.

The CDMA demodulator despreads the signal with appropriate processing to reduce or exploit multipath propagation effects. The radio links support multiple traffic channels with data rates of 8, 16, 32, 64, 128 and 144 kb/s. The physical channel to which a traffic channel is connected operates with a 64 k symbol/sec rate. Other data rates may be supported, and forward error correction (FEC) coding can be employed. For the described embodiment, FEC with a coding rate of ½ and a constraint length 7 is used. Other rates and constraint lengths can be used consistent with the code generation techniques employed.

Referring again to FIG. **1**, the RCS **104** interfaces to the RDU **102** through a plurality of RF links or terrestrial links **131**, **132**, **137** with, for example, 1.533 Mb/s DS1, 2.048 Mbs/E1; or HDSL formats to receive and send digital data signals. While these are typical telephone company standardized interfaces, the present invention is not limited to these digital data formats only. The exemplary RCS line interface (not shown in FIG. **1**) translates the line coding (such as HDB3, B8ZS, AMI) and extracts or produces framing information, performs alarms and facility signaling functions, as well as channel specific loop-back and parity check functions. This provides 64 kb/s PCM encoded or 32 kb/s ADPCM encoded telephone traffic channels or ISDN channels to the RCS **104**, **105**, **110** for processing as will be described in greater detail hereinafter. Other voice compression techniques can be used consistent with the sequence generation techniques.

The system of the present invention also supports bearer rate modification between the RCS **104** and the subscriber unit **111** for both POTS service and ISDN service. The subscriber units **111–118** may interface with a telephone unit **170**, a local switch (PBX) **171**, a data terminal **172**, an ISDN interface **173** or other types of equipment shown in FIGS. 2A–2H. The input from the telephone unit **170** may include voice, voiceband data and signaling. Although the present invention is applicable to the communications between a plurality of subscriber units **111–118** and a plurality of RCSs **104–110**, reference hereinafter will be made to a particular subscriber unit and RCS for simplicity. If the signals input into the subscriber unit are not digital, the subscriber unit **111** translates the analog signals into digital sequences for transmission to the RCS **104**. The subscriber unit **112** encodes voice data with techniques such as ADPCM at rates of 32 kb/s or lower. The RCS **104** detects voiceband data or facsimile data with rates above 4.8 kb/s to modify the bearer rate of the traffic channel for unencoded transmission. Also

A-law, u-law, or no companding of the signal may be performed before transmission. As is well known to those of skill in the art, data compression techniques for digital data such as idle flag removal may also be used to conserve capacity and minimize interference.

The transmit power level of the radio interface between the RCS **104** and the subscriber unit **111** is controlled using a different closed loop power control method for the downlink and uplink directions. The automatic forward power control (AFPC) method determines the downlink transmit power level and the automatic reverse power control (ARPC) method determines the uplink transmit power level. The logical control channel by which the subscriber unit **111** and the RCS **104** transfer power control information operates at an update rate of at least a 16 kHz. Other embodiments may use a faster or slower update rate, for example 64 kHz. These algorithms ensure that the transmit power of a user maintains an acceptable bit-error rate (BER), maintain the system power at a minimum to conserve power and maintain the power level of the subscriber unit **111** as received by the RCS **104** at a nearly equal level.

The system also uses an optional maintenance power control method during the inactive mode of the subscriber unit **111**. When the subscriber unit **111** is inactive or powered-down to conserve power, the subscriber unit **111** occasionally activates to adjust its initial transmit power level setting in response to a maintenance power control signal from the RCS **104**. The maintenance power control signal is determined by the RCS **104** by measuring the received power level of the subscriber unit **111** and present system power level and calculating the necessary initial transmit power. The method shortens the channel acquisition time of the subscriber unit **111** to begin a communication and prevents the transmit power level of the subscriber unit **111** from becoming too high and interfering with other channels during the initial transmission before the closed loop power control reduces the transmit power.

The RCS **104** obtains synchronization of its clock from an interface line such as, but not limited to, E1, T1, or HDSL interfaces. The RCS **104** can also generate its own internal clock signal from an oscillator which may be regulated by a global positioning system (GPS) receiver. The RCS **104** generates a global pilot code, which can be acquired by the remote subscriber unit **111**. All transmission channels of the RCS **104** are synchronized to the global pilot channel. The spreading code phases of code generators (not shown in FIG. 1) used for logical communication channels within the RCS **104** are also synchronized to the spreading code phase of the global pilot channel. Similarly, all subscriber units **111**–**118** which receive the global pilot code of the RCS **104** synchronize the spreading and de-spreading code phases of their code generators to the global pilot code.

Typically, a prior art channel is regarded as a communications path which is part of an interface and which can be distinguished from other paths of that interface without regard to its content. However, for CDMA communications, separate communications paths are distinguished by their content. All logical channels and subchannels of the present invention are mapped to a common 64 kilo-symbols per second (ksym/s) QPSK stream. Some channels are synchronized to associated pilot codes which are generated from, and perform a similar function to, the global pilot code. The system pilot signals are not considered logical channels.

Several logical communication channels are used over the RF communication link between the RCS **104** and the subscriber unit **111**. Each logical communication channel either has a fixed, pre-determined spreading code or a dynamically assigned spreading code. For both predetermined and assigned codes, the code phase is synchronized with the global pilot code.

The spreading codes are specified by the seeds used to generate the codes. A pool of "primary seeds" exists within the RDU **102**, a portion of which comprise global primary seeds and the remainder comprise assigned primary seeds. The RDU **102** allocates these primary seeds to the RCSs **104** on an as-needed basis. A global primary seed generates all of the global channel codes for use by an RCS **104** within a cell. However, assigned primary seeds are used to generate secondary assigned seeds. One primary assigned seed generates fifty-seven (57) secondary assigned seeds. Each secondary assigned seed is input into the code generators within the RCS **104** and the subscriber unit **111** to generate a set of assigned channel codes to support each communication link. In the preferred embodiment, each RCS **104** is given one global primary seed for generating global channel codes and two primary assigned seeds. Accordingly, the RCS **104** and its corresponding subscriber units **111**–**118** may generate up to 114 secondary assigned seeds. Each secondary assigned seed is assigned by the RCS **104** to generate the codes for an active link, thereby permitting enough codes for up to 114 simultaneous communication links.

Logical communication channels are divided into two groups: 1) global channels; and 2) assigned channels. The global channel group includes channels which are either transmitted from the RCS **104** to all subscriber units **111**–**118** or from any subscriber unit **111**–**118** to the RCS **104** regardless of the identity of the subscriber unit **111**–**118**. Channels in the assigned channels group are those channels dedicated to communication between the RCS **104** and a particular subscriber unit **111**.

With respect to the global channel group, the global channel group provides for: 1) broadcast control logical channels, which provide point-to-multi-point services for broadcasting messages to all subscriber units **111**–**118** and paging messages to subscriber units **111**–**118**; and 2) access control logical channels which provide point-to-point services on global channels for subscriber units **111**–**118** to access the system and obtain assigned channels. The RCS **104** of the present invention has one broadcast control logical channel and multiple access control logical channels. A subscriber unit **111**–**118** of the present invention has at least one broadcast control logical channel and at least one access control logical channel.

The global logical channels controlled by the RCS **104** are the fast broadcast channel (FBCCH) which broadcasts fast changing information concerning which services and which access channels are currently available, and the slow broadcast channel (SBCCH) which broadcasts slow changing system information and paging messages.

The subscriber unit **111** uses an access channel (AXCH) to begin communications with the RCS **104** and gain access to assigned channels. Each AXCH is paired with a control channel (CTCH) which is sent from the RCS **104** to the subscriber unit **111**. The CTCH is used by the RCS **104** to acknowledge and reply to access attempts by the subscriber unit **111**. The short access pilot (SAXPT) and the long access pilot (LAXPT) are transmitted synchronously with AXCH to initiate access and to provide the RCS **104** with a time and phase reference. The SAXPT is transmitted by the subscriber unit **111** while it ramps up its transmit power to initiate access to the RCS **104**. Since the SAXPT is a relatively short code it permits the RCS **104** to detect the

subscriber unit 111 quickly and avoids power overshoot by the subscriber unit 111. Further detail regarding transmit power ramp-up using the SAXPT is described in more detail in an application entitled A METHOD OF CONTROLLING INITIAL POWER RAMP-UP IN CDMA SYSTEMS BY USING SHORT CODES, Ser. No. 08/670,162; filed Jun. 27, 1996 which is herein incorporated by reference as if fully set forth. Until the SAXPT is detected by the RCS 104, subscriber unit 111 does not send any other signal. Once the SAXPT is detected, the subscriber unit 111 starts transmitting the LAXPT which provides the RCS 104 with a time and phase reference and permits the RCS 104 to determine the channel impulse response.

With respect to the assigned channel group, this group contains the logical channels that control a single communication link between the RCS 104 and the subscriber unit 111. When an assigned channel group is formed, a pair of power control logical message channels for each of the uplink and downlink connections is established and one or more pairs of traffic channels, depending on the type of connection, is established. The bearer control function performs the required forward error control, bearer rate modification and encryption functions.

Each subscriber unit 111–118 has at least one assigned channel group when a communication link is established, and each RCS 104–110 has multiple assigned channel groups, one for each communication link in progress. An assigned channel group of logical channels is created for a communication link upon successful establishment of the communication link. The assigned channel group includes encryption, FEC coding, and multiplexing on transmission, and decryption, FEC decoding and demultiplexing on reception.

Each assigned channel group provides a set of communication link oriented point-to-point services and operates in both directions between a specific RCS 104 and a specific subscriber unit 111. An assigned channel group formed for a communication link can control more than one bearer over the RF communication channel associated with a single communication link. Multiple bearers are used to carry distributed data such as, but not limited to, ISDN. An assigned channel group can provide for the duplication of traffic channels to facilitate switchover to 64 kb/s PCM for high speed facsimile and modem services for the bearer rate modification function.

The assigned logical channels formed upon a successful communication link and included in the assigned channel group are dedicated signaling channel order wire (OW), APC channel and one or more traffic channels (TRCH) which are bearers of 8, 16, 32, or 64 kb/s depending on the service supported. For voice traffic, moderate rate coded speech ADPCM or PCM can be supported on the traffic channels. For ISDN service types, two 64 kb/s TRCHs form the B channels and one 16 kb/s TRCH forms the D channel. Alternatively, the APC subchannel may either be separately modulated on its own CDMA channel, or may be time division multiplexed with a traffic channel or OW channel.

Each subscriber unit 111–118 of the present invention supports up to three simultaneous traffic channels. A subscriber unit is preferably commissioned to be a POTS subscriber unit 112 or an ISDN subscriber unit 115. Although POTS subscriber unit 112 does not support ISDN service in accordance with the present invention, bandwidth resources can be dynamically allocated for either service type. For example, a POTS subscriber unit 112 can set up an additional POTS line and tear it down, or an ISDN subscriber unit 115 can dynamically add B channel-carrying bearers or tear them down. For dynamic bandwidth allocation of a POTS service, an active 32 kb/s ADPCM service modifies the bearer type from 32 kb/s to 64 kb/s unencoded data to support facsimile transmission. The presence of a facsimile call is determined by the RCS 104 by monitoring the existence of the 2100 Hz answer tone.

For dynamic bandwidth allocation of ISDN service, the RCS 104 monitors the ISDN D channel messages to determine when a B channel is requested and when it should be torn down. Once the RCS 104 determines the need for changing the bearer channel allocation, the RCS 104 initiates the dynamic bearer allocation procedure which will be described in greater detail hereinafter. The mapping of the three logical channels for TRCHs to the user data is shown below in Table 1:

TABLE 1

Mapping of service types to the three available TRCH channels

Service	TRCH(0)	TRCH(1)	TRCH(2)
16 kb/s POTS	TRCH/16	not used	not used
32 + 64 kb/s POTS (during BCM)	TRCH/32	TRCH/64	not used
32 kb/s POTS	TRCH/32	not used	not used
64 kb/s POTS	not used	TRCH/64	not used
ISDN D	not used	not used	TRCH/16
Digital LL @ 64 kb/s	TRCH/64	not used	not used
Digital LL @ 2 × 64 kb/s	TRCH/64	TRCH/64	not used
Analog LL @ 64 kb/s	TRCH/64	not used	not used

A subscriber unit 200 made in accordance with the present invention is generally shown in FIG. 3. The subscriber unit 200 includes a receiver section 202 and a transmitter section 204. An antenna 206 receives a signal from RCS 104, which is filtered by a band-pass filter 208 having a bandwidth equal to twice the chip rate and a center frequency equal to the center frequency of the spread spectrum system's bandwidth. The output of the filter 208 is down-converted by a mixer 210 to a baseband signal using a constant frequency (Fc) local oscillator. The output of the mixer 210 is then spread spectrum decoded by applying a PN sequence for each logical channel to a mixer 212 within the PN Rx generator 214. The output of the mixer 212 is input to a codec 218 which interfaces with the communicating entity 220.

A baseband signal from the communicating entity 220, for example the equipment shown in FIGS. 2A–2H, is pulse code modulated by the codec 218. Preferably, a 32 kb/s adaptive pulse code modulation (ADPCM) is used. The PCM signal is applied to a mixer 222 within a PN Tx generator 224. The mixer 222 multiplies the PCM data signal with the PN sequence for each logical channel. The output of the mixer 222 is applied to low-pass filter 226 whose cutoff frequency is equal to the system chip rate. The output of the filter 226 is then applied to a mixer 228 and suitably up-converted, as determined by the carrier frequency Fc applied to the other terminal. The up-converted signal is then passed through a band-pass filter 230 and to a broadband RF amplifier 232 which drives an antenna 234. Although two antennas 206, 234 are shown, the preferred embodiment includes a diplexer and a single antenna for transmission and reception. The digital signal processor (DSP) 236 controls the acquisition process as well as the Rx and Tx PN generators 214, 224.

The base station 101, which includes a plurality of RCSs 104, 105, 110 made in accordance with the present invention is shown in FIG. 4. For simplicity, only one RCS 104 is

shown. The base station 101 includes a receiver section 302 and a transmitter section 304. An antenna 306 receives a signal from the subscriber unit, which is filtered by a band-pass filter 308 having a bandwidth equal to twice the chip rate and a center frequency equal to the center frequency of the spread spectrum system's bandwidth. The output of the filter 308 is down-converted by a mixer 310 to a baseband signal using a constant frequency (Fc) local oscillator. The output of the mixer 310 is then spread spectrum decoded at each modem by applying a PN sequence to a mixer 312 within the PN Rx generator 314. The output of the mixer 316 is then forwarded to the RDU 318.

A baseband signal is received from the RDU 318. Preferably, a 32 kb/s ADPCM signal is used. The ADPCM or PCM signal is applied to a mixer 322 within a PN Tx generator 324. The mixer 322 multiplies the ADPCM or PCM data signal with the PN sequence. The output of the mixer 322 is applied to low-pass filter 326 whose cutoff frequency is equal to the system chip rate. The output of the filter 326 is then applied to a mixer 328 and suitably up-converted, as determined by the carrier frequency Fc applied to the other terminal. The up-converted signal is then passed through a band-pass filter 330 and to a broadband RF amplifier 332 which drives an antenna 334. Although two antennas 306, 334 are shown, the preferred embodiment includes a diplexer and only one antenna for transmission and reception. The digital signal processor (DSP) 336 controls the acquisition process as well as the Rx and Tx PN generators 314, 324.

The system provides a wireless link between the RCS 104 and the plurality of subscriber units 111–118. In order to conserve as much bandwidth as possible, the system selectively allots the bandwidth required for supporting the data transmission rate required by particular communication. In this manner, the system ensures that the bandwidth is utilized efficiently. For example, referring back to Table 1, voiced communications may be effectively transmitted across a 32 kb/s adaptive pulse code modulation (ADPCM) channel. However, a high speed facsimile or data modem signal requires at least a 64 k/bs PCM signal to reliably transmit the communication. Additionally, although a subscriber unit 115 has paid for ISDN service, which includes two 64 kb/s B channels and one 16 kb/s channel, the entire ISDN capacity is rarely utilized at all times. Many different data transmission rates may also be utilized by originating and terminating nodes.

The originating and terminating nodes may comprise computers, facsimile machines, automatic calling and answering equipment, data networks or any combination of this equipment. For robust communication of data it is imperative to ensure that the communication system switches to the data transmission rate required by the communicating nodes prior to the transmission of any data. The system must be able to effectively allocate bandwidth and dynamically switch between these data communication rates on demand by the user. Modification of the transmission rate from a low rate (that supports voice communication) to a high rate (that supports encoded data communication) ensures that data will be reliably and quickly transmitted over a communication channel.

Additionally, if an ISDN D channel is presently allocated and one or two B channels are required, the system must ensure that the code generators are activated in order to support the communication.

For POTS, there are two basic scenarios where the bearer channel (TRCH channel) is either modified or a new bearer channel is added or torn down. First, the bearer channel is modified from 32 kb/s coded ADPCM type to 64 kb/s uncoded PCM service to support a facsimile transmission. Second, a new bearer channel is added or torn down when the subscriber goes off hook while an OA&M (overhead, administration and maintenance) call is in progress, or when an OA&M call is initiated while a POTS call is in progress. While an OA&M silent call is in progress, the subscriber unit 112 can determine that the user is initiating a new POTS call by monitoring the changes at the A/B interface between the subscriber unit 112 and the communication equipment 170 (on-hook/off-hook sensor). More detail regarding the dynamic allocation of bandwidth for POTS may be found in an application entitled CODE DIVISION 20 MULTIPLE ACCESS (CDMA) COMMUNICATION SYSTEM, Patent Application Serial No. Not Yet Known, filed Mar. 11, 1997, which is a continuation-in-part of Ser. No. 08/669,775, filed Jun. 27, 1996 by Lomp et al., which is incorporated herein by reference as if fully set forth.

For ISDN service, the dynamic bandwidth allocation refers to selective allocation of the D and B channels in a D, D and B, or D and 2B bearer channel configuration as needed and tearing them down when they are idle. The ISDN D channel carries control messaging and cannot be torn down while the ISDN call is still active. Accordingly, dynamic bandwidth allocation for ISDN service only relates to the addition and tearing down of B channels.

The procedure 400 for dynamic allocation of bandwidth for ISDN service in accordance with the present invention will be explained in greater detail with reference to FIG. 5. When an ISDN call is initiated, the D channel is established first (step 402). The bandwidth required for the particular application is communicated from the calling ISDN equipment to the called ISDN equipment through messages on the D channel (step 404). These messages are in HDLC format and the RCS 104 monitors these messages via an HDLC interface (step 406). Once the RCS 104 determines how many B channels are required (step 408) it initiates establishment of these bearer channels over the air interface (step 410). The RCS continues monitoring the HDLC messages on the D channel during the ISDN call (step 412) and determines if additional B channels are to be switched in or out. In case that additional B channels should be switched in or out, the RCS 104 initiates the establishment or tearing down of the bearer channels over the air interface (step 414).

A flow diagram showing simplified procedure 600 of the bearer channel establishment will be described with reference to FIGS. 6A and 6B. The subscriber unit 111 quickly ramps up its transmit power (step 602) while sending the SAXPT (step 604). When the RCS 104 detects the SAXPT (step 606), it turns the traffic light bit to "red" on the FBCCH (step 608) to signal to the subscriber unit 111 that it has been detected. The RCS 104 transmits the FBCCH (step 610). The subscriber unit 111 monitors the FBCCH (step 612) and it stops the fast ramp-up when it sees the "traffic light" turn red on the FBCCH (step 614). The subscriber unit 111 then continues a slow ramp-up of its transmit power (step 616) while transmitting the LAXPT (step 618). When the RCS 104 acquires the LAXPT (step 620), it informs the subscriber unit 111 via the SYNC-OK message on CTCH (step 622). This completes the transmit power ramping up part of the access procedure.

After the subscriber unit 111 receives the SYNC-OK message on the CTCH (step 624), it sends the access request message on the AXCH (step 626). Upon receiving the request (step 628) the RCS 104 confirms receipt of the AXCH message with a message on CTCH (step 630), which

includes the assigned code seed. The subscriber unit 111 detects and acknowledges the bearer confirmation message that carries the assigned code seed on the AXCH (steps 632 and 634), which the RCS 104 detects (step 636). The code switchover is now negotiated and subscriber unit 111 and RCS 104 simultaneously switch to using the assigned code (steps 638 and 640). The bearer channel is now established.

The layered protocol of the communications between the subscriber unit 111 and the RCS 104 is shown in FIG. 7 along with its correspondence to the layers of the Open Systems Interconnection (OSI) reference model. The physical (PHL) layer performs the following functions: 1) generation of CDMA codes; 2) synchronization between transmitter and receiver; 3) providing bearers to the Medium Access Control (MAC) layer; 4) spreading and transmission of bits on a CDMA code specified by the MAC and at a power level specified by the MAC; 5) measurement of received signal strength to allow automatic power control; and 6) generation and transmission of pilot signals. The MAC layers performs the following functions: 1) encoding and decoding for forward error correction (FEC); 2) assignment of CDMA codes; 3) encryption and decryption; 4) providing bearers which are encrypted and error-corrected as appropriate; 5) framing, error checking and discrimination of MAC peer to peer messages and data; 6) link control (DLC) frames; and 7) processing of automatic power control information. The data link control layer (DLC) provides an error-free link between higher level layers of the protocol stack.

As shown in FIG. 8A, the signaling between the subscriber unit 111 and the RCS 104 involves the MAC and DLC layers of the protocol. Once the bearer channel for POTS service is established as described above, the service is available until it is unchanged until it is torn down or unless it has to be modified to support a facsimile transmission or a second call, in the case of a simultaneous OA&M call and POTS call. When there is an OA&M call in progress and the subscriber unit 111 initiates a POTS service call, the procedure as shown in FIG. 8A is entered. This figure illustrates the simplified bearer switching method as initiated by the subscriber unit 111. The messages go between the data link control layer (DLC), medium access control layer (MAC) of the subscriber unit 111, and the corresponding layers in the RCS 104. First, the DLC layer of the subscriber unit 111 initiates a switch request to the MAC layer of the subscriber unit 111, which refers this switch request to the MAC layer of the RCS 104. The RCS 104 sends a confirmation over the MAC layer to the subscriber unit 111 and also sends a switch indication to the DLC layer of the RCS 104. In the subscriber unit 111, the switch confirmation sent from the RCS 104 over the MAC layer is forwarded to the DLC layer of the subscriber unit 111.

When there is a POTS service call in progress and the RCS 104 initiates an OA&M call to the same subscriber unit 111, the procedure as shown in FIG. 8B is entered. This figure illustrates the simplified bearer switching method as initiated by the RCS 104. The RCS 104 initiates a switch indication message over the MAC layer to the subscriber unit 111. The subscriber unit 111 then relays this message via the DLC layer.

The bearer channel establishment for ISDN will be explained with reference to FIGS. 9A and 9B. Steps 902–940 are the same as the corresponding steps 602–640 in FIGS. 6A and 6B. However, several additional steps are required after the subscriber unit 111 and the RCS 104 both switch to the assigned codes (steps 938 and 940). Once the subscriber unit 111 and RCS 104 switch to assigned codes (steps 938 and 940) the ISDN D channel becomes active. At this point the S/T interface between the subscriber unit 111 and the ISDN equipment is already active. The RCS 104 starts monitoring the D channel messages (step 942), which are in HDLC format. Upon detecting that one or more B channels are needed for the particular application (step 944) the RCS 104 initiates establishment of these bearer channels over the air interface. The process is then continued in accordance with the procedure shown in FIG. 5. The MAC and DLC message flow for this procedure is the same as in FIG. 8B.

The bearer channels for POTS and ISDN is switched in or out via the same message flow. Whether the bearer channel is switched in or out is indicated by appropriate values in corresponding fields of the D channel messages. Therefore the flow diagram in FIG. 8B apply to both dynamic switching in of bearer channels as well as dynamic switching out of bearer channels.

Although the invention has been described in part by making detailed reference to certain specific embodiments, such details is intended to be instructive rather than restrictive. It will be appreciated by those skilled in the art that many variations may be made in the structure and mode of operation without departing from the spirit and scope of the invention as disclosed in the teachings herein.

What is claimed is:

1. A wireless digital CDMA communication system, including a base station and at least one subscriber unit, for transmitting a plurality of communications having independent data rates between a base station and a subscriber unit, the system comprising:

at least one base station comprising:

first means for processing a first communication for transmitting to said at least one subscriber unit including first means for determining the data rate required to support said first communication; and

first transmission means for transmitting communications at one of said plurality of data rates having data rate selection means responsive to said first determining means;

and at least one subscriber unit comprising:

means for establishing a communication channel having a capacity of a first data communication rate;

means for communicating at a second data communication rate, wherein said first data communication rate is higher than said second data communication rate;

second means for processing a second communication for transmitting to said base station including second means for determining the data rate required to support said communication;

second transmission means for transmitting communications at one of a plurality of data rates including data rate selection means responsive to said second determining means; and

means for establishing a ISDN channel including two B channels and a D channel; wherein said system selectively utilizes said B and said D channels depending upon the later rate required to support said desired communication.

2. A wireless digital code division multiple access (CDMA) communication system for dynamically switching data communication rates required by users, the system comprising:

at least a first communication station including:

means for establishing communication channels of predetermined data transmission rates;

means for transmitting a communication at an initial data rate using at least one channel;

means for monitoring said communication and determining an adjusted data rate desired for continued support of said communication;

means for allocating a sufficient number of channels for the communication based on the adjusted data rate such that the sum of the data rates of the allocated channels is at least equal to the adjusted data rate and is not greater than the adjusted data rate plus a predetermined rate; and

means for continuing the transmission of said communication within said allocated channels whereby said station dynamically adds or tears down channels for said communication by changing the number of allocated channels during said communication.

3. A wireless digital code division multiple access (CDMA) system as in claim 2 wherein said establishing means establishes D channels at a first data rate and B channels at a second data rate which is greater than said first data rate.

4. A wireless digital code division multiple access (CDMA) system as in claim 3 wherein said first data rate is 16 kb/s and said second date rate is 64 kb/s.

5. A wireless digital code division multiple access (CDMA) system as in claim 4 wherein the communication is an ISDN communication and said allocating means allocates a single D channel and a sufficient number of B channels for continued transmission of the communication from said station and said predetermined rate is equal to said second data rate.

6. A wireless digital code division multiple access (CDMA) system as in claim 3 wherein the communication is an ISDN communication and said allocating means allocates a single D channel and a sufficient number of B channels for continued transmission of the communication from said station and said predetermined rate is equal to said second data rate.

7. A wireless digital code division multiple access (CDMA) system as in claim 2 wherein a set of assigned channel codes are assigned for the communication and the allocating means allocates channels having codes within said assigned set.

8. A wireless digital code division multiple access (CDMA) system as in claim 2 further comprising:

at least a second communication station including:

means for receiving from said first station the communication within said allocated channels.

9. A wireless digital code division multiple access (CDMA) as in claim 8 wherein:

said second communication station further includes:

means for establishing return communication channels of different data transmission rates;

means for monitoring a return communication and determining a desired return data rate;

means for allocating a sufficient number of channels for the return communication based on desired the return data rate such that the total data rate of the allocated return channels is at least equal to the desired return data rate and is not greater than the desired return data rate plus a predetermined rate; and

means for transmitting the return communication within said allocated return channels; and

said first communication station includes means for receiving the return communication within said allocated return channels.

10. A wireless digital code division multiple access (CDMA) system as in claim 9 wherein each said establishing means establishes D channels at a first data rate and B channels at a second data rate which is greater than said first data rate.

11. A wireless digital code division multiple access (CDMA) system as in claim 10 wherein said first data rate is 16 kb/s and said second date rate is 64 kb/s.

12. A wireless digital code division multiple access (CDMA) system as in claim 10 wherein the communication and return communication are an ISDN communication; each said allocating means allocates a single D channel and a sufficient number of B channels; and said predetermined rates are equal to said second data rate.

13. A wireless digital code division multiple access (CDMA) as in claim 8 wherein said first communication station is a base station which further comprises:

a physical layer generating CDMA codes, synchronizing between said base station and subscriber units, providing bearers, spreading and transmitting bits on a CDMA code, measuring received signal strength to permit automatic power control, and generating transmission of pilot signals;

a medium access control (MAC) layer encoding and decoding for forward error correcting, assigning CDMA codes, encrypting and decrypting communication signals, encrypting and error-correcting to the bearers provided by the physical layer, framing, error checking and discriminating medium access control peer to peer messages and data, linking control frames, and processing automatic control information; and

a data link control layer providing an error-free link among the layers, wherein the data link control layer initiates changes in the allocation of channels based on determining the minimum desired data rate for communications channels via physical layer.

14. A wireless digital code division multiple access (CDMA) communication system as in claim 13 wherein said second communication station is a subscriber unit which further comprises:

a physical layer generating CDMA codes; synchronizing between said base station and said subscriber unit; providing bearers; spreading and transmitting bits on a CDMA code; measuring received signal strength to permit automatic power control; and generating transmission of pilot signals;

a MAC layer encoding and decoding for forward error correcting; assigning CDMA codes; encrypting and decrypting communication signals; encrypting and error-correcting to the bearers provided by the physical layer; framing; error checking and discriminating medium access control, peer to peer messages and data; linking control frames; and processing automatic control information; and

a data link control layer providing an error-free link among the layers, wherein the data link control layer initiates changes in the allocation of channels based on determining the minimum desired data rate for communications channels via physical layer.

15. A method for allocating bandwidth and dynamically switching between different bandwidths in a communication station of a code division multiple access (CDMA) system based upon the data communication rates required by a user comprising:

a) transmitting a communication at an initial data rate using at least one channel;

b) monitoring said communication and determining an adjusted data rate desired for continued support of said communication;

c) allocating a sufficient number of channels for the communication based on the adjusted data rate such that the total data rate of the allocated channels is at least equal to the adjusted data rate and is not greater than the adjusted data rate plus a predetermined rate; and

d) continuing transmission of said communication within said allocated channels whereby said communication station dynamically adds or tears down channels for said communication by changing the number of allocated channels during said communication.

16. A method according to claim **15** wherein steps b, c, and d are repeated during transmission of said communication to determine new adjusted data rates and new allocations of channels during said communication.

17. A method according to claim **15** wherein said communication station establishes D channels at a first data rate and B channels at a second data rate which is greater than said first data rate and said allocating includes the allocation of a single D channel and a sufficient number of B channels using said second data rate as said predetermined rate.

18. A method according to claim **17** wherein said communication station establishes D channels at a data rate of 16 kb/s and said B channels at a data rate of 64 kb/s.

* * * * *

US005799010A

United States Patent [19]

Lomp et al.

[11] Patent Number: 5,799,010

[45] Date of Patent: Aug. 25, 1998

[54] CODE DIVISION MULTIPLE ACCESS (CDMA) COMMUNICATION SYSTEM

[75] Inventors: **Gary Lomp**, Centerpot; **John Kowalski**, Hempstead; **Fatih Ozluturk**, Port Washington; **Avi Silverberg**, Commack; **Robert Regis**, Huntington; **Michael Luddy**, Sea Cliff, all of N.Y.; **Alexander Marra**, Hoboken, N.J.; **Alexander Jacques**, Mineola, N.Y.

[73] Assignee: **Interdigital Technology Corporation**, Wilmington, Del.

[21] Appl. No.: **669,775**

[22] Filed: **Jun. 27, 1996**

Related U.S. Application Data

[60] Provisional application No. 60/000,775 Jun. 30, 1995.

[51] **Int. Cl.**[6] **H04J 13/02**; H04B 7/216

[52] **U.S. Cl.** **370/335**; 370/342; 375/208

[58] **Field of Search** 370/203, 208, 370/209, 320, 328, 329, 335, 342, 441, 479; 375/200, 206, 208, 354, 362, 365, 367; 455/31.1, 33.1, 38.1, 53.1, 54.1, 67.1, 226.1, 422, 507, 517

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Primary Examiner—Alpus H. Hsu
Assistant Examiner—Kwang B. Yao
Attorney, Agent, or Firm—Ratner & Prestia

[57] **ABSTRACT**

A multiple access, spread-spectrum communication system processes a plurality of information signals received by a Radio Carrier Station (RCS) over telecommunication lines for simultaneous transmission over a radio frequency (RF) channel as a code-division-multiplexed (CDM) signal to a group of Subscriber Units (SUs). The RCS receives a call request signal that corresponds to a telecommunication line information signal, and a user identification signal that identifies a user to receive the call. The RCS includes a plurality of Code Division Multiple Access (CDMA) modems, one of which provides a global pilot code signal. The modems provide message code signals synchronized to the global pilot signal. Each modem combines an information signal with a message code signal to provide a CDM processed signal. The RCS includes a system channel controller is coupled to receive a remote call. An RF transmitter is connected to all of the modems to combine the CDM processed signals with the global pilot code signal to generate a CDM signal. The RF transmitter also modulates a carrier signal with the CDM signal and transmits the modulated carrier signal through an RF communication channel to the SUs. Each SU includes a CDMA modem which is also synchronized to the global pilot signal. The CDMA modem despreads the CDM signal and provides a despread information signal to the user. The system includes a closed loop power control system for maintaining a minimum system transmit power level for the RCS and the SUs, and system capacity management for maintaining a maximum number of active SUs for improved system performance.

9 Claims, 35 Drawing Sheets

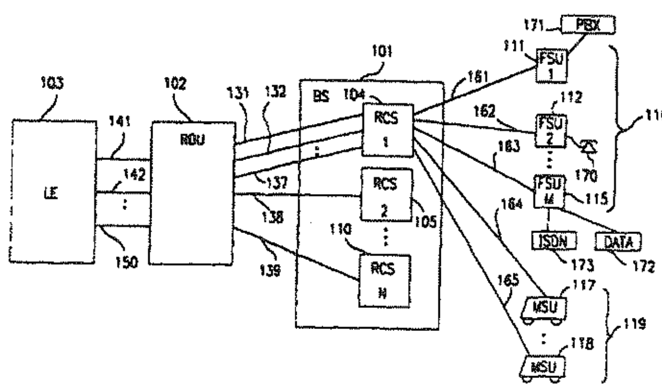

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FIG. 1

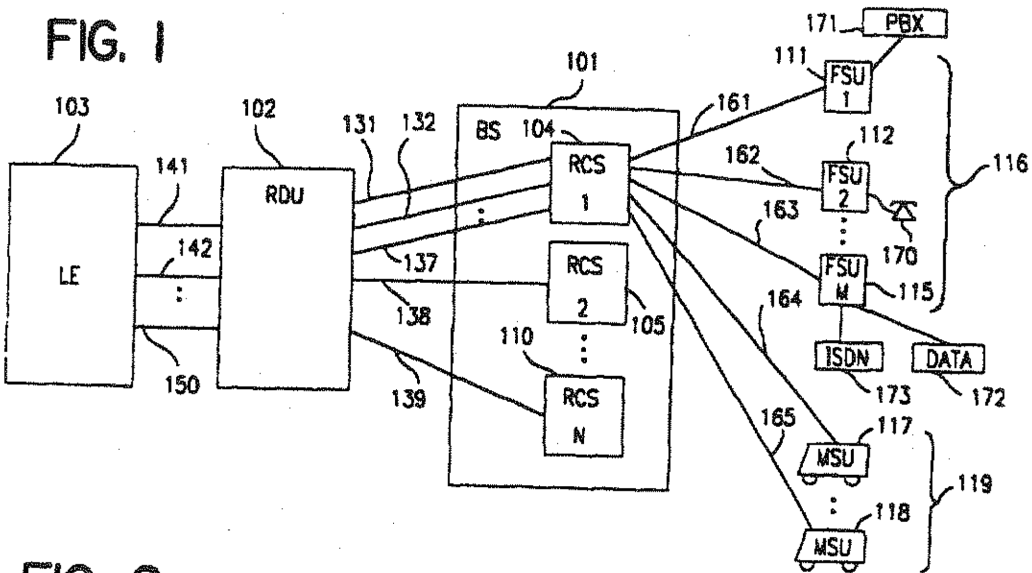


FIG. 2a

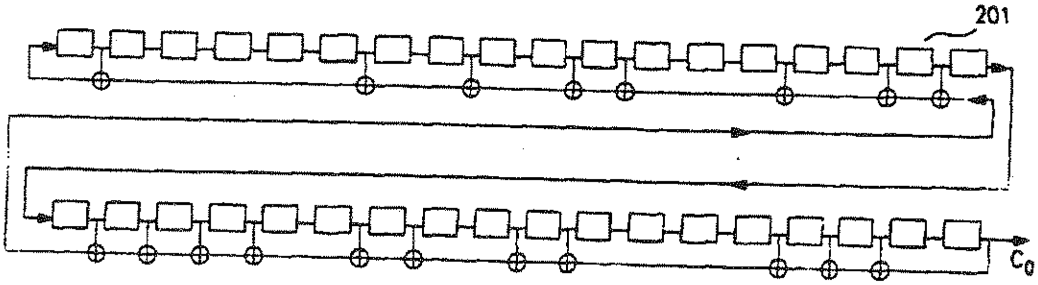


FIG. 2b

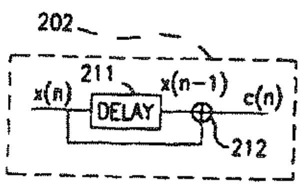
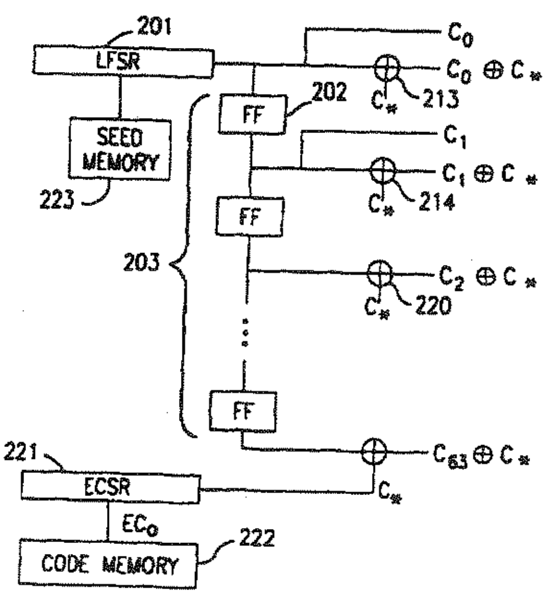


FIG. 2c



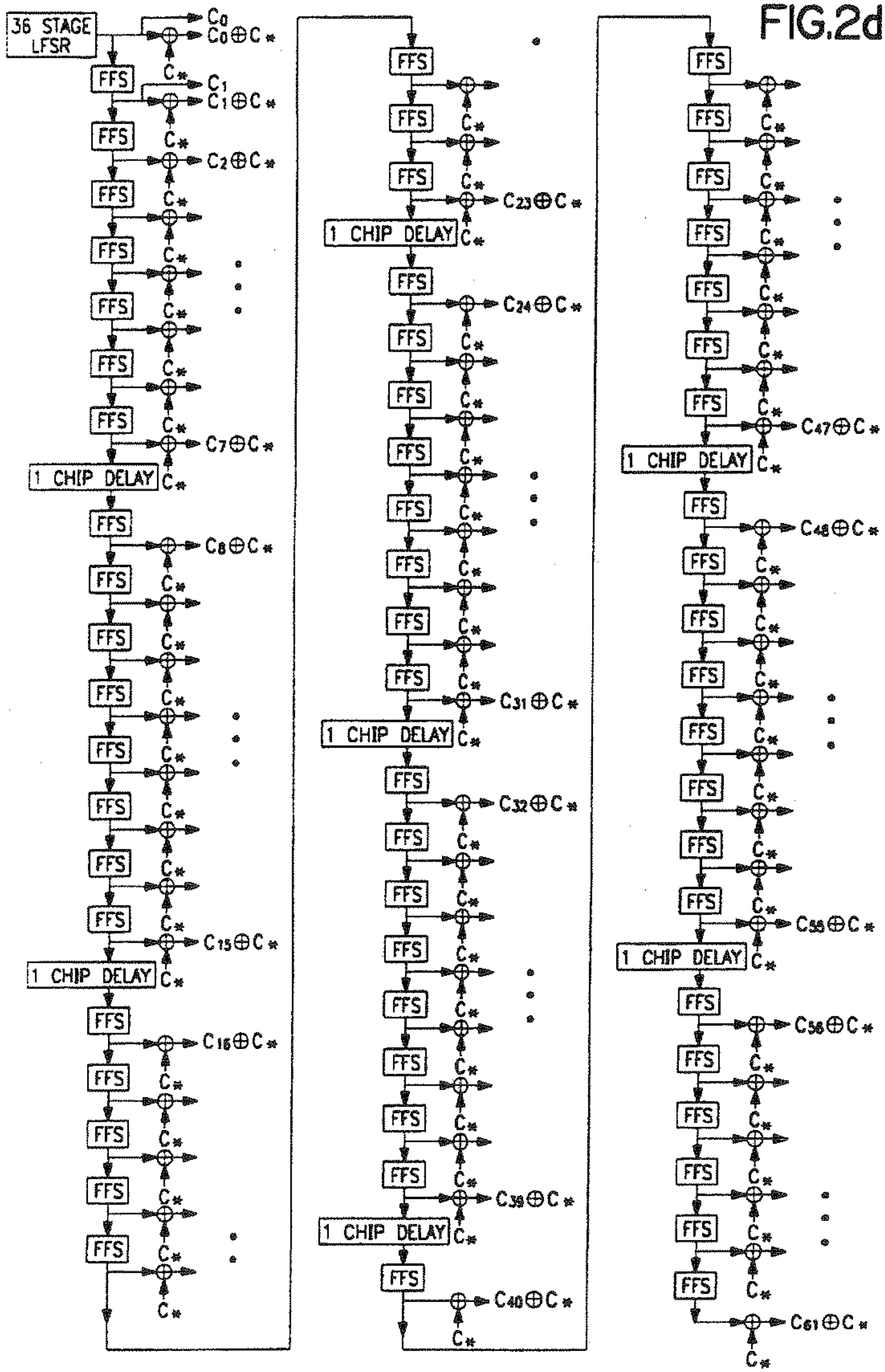

36 STAGE LFSR
FFS
1 CHIP DELAY
C_0
$C_0 \oplus C_*$
C_1
$C_1 \oplus C_*$
$C_2 \oplus C_*$
$C_7 \oplus C_*$
$C_8 \oplus C_*$
$C_{15} \oplus C_*$
$C_{16} \oplus C_*$
$C_{23} \oplus C_*$
$C_{24} \oplus C_*$
$C_{31} \oplus C_*$
$C_{32} \oplus C_*$
$C_{39} \oplus C_*$
$C_{40} \oplus C_*$
$C_{47} \oplus C_*$
$C_{48} \oplus C_*$
$C_{55} \oplus C_*$
$C_{56} \oplus C_*$
$C_{61} \oplus C_*$
C_*

FIG.2d

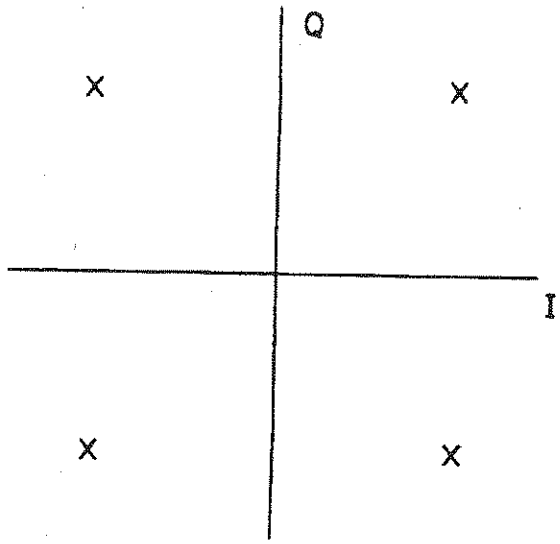


FIG. 3a

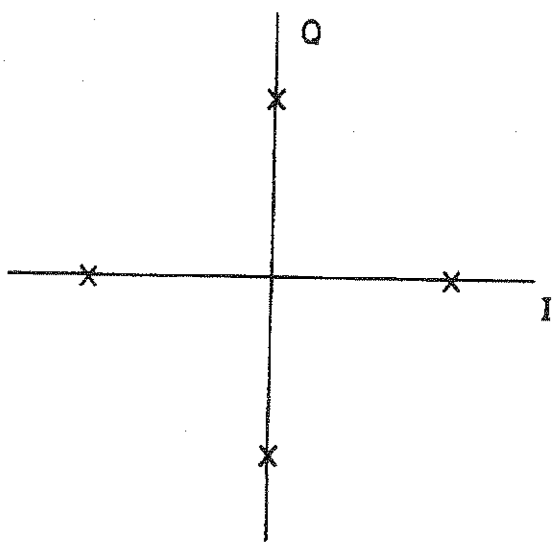


FIG. 3b

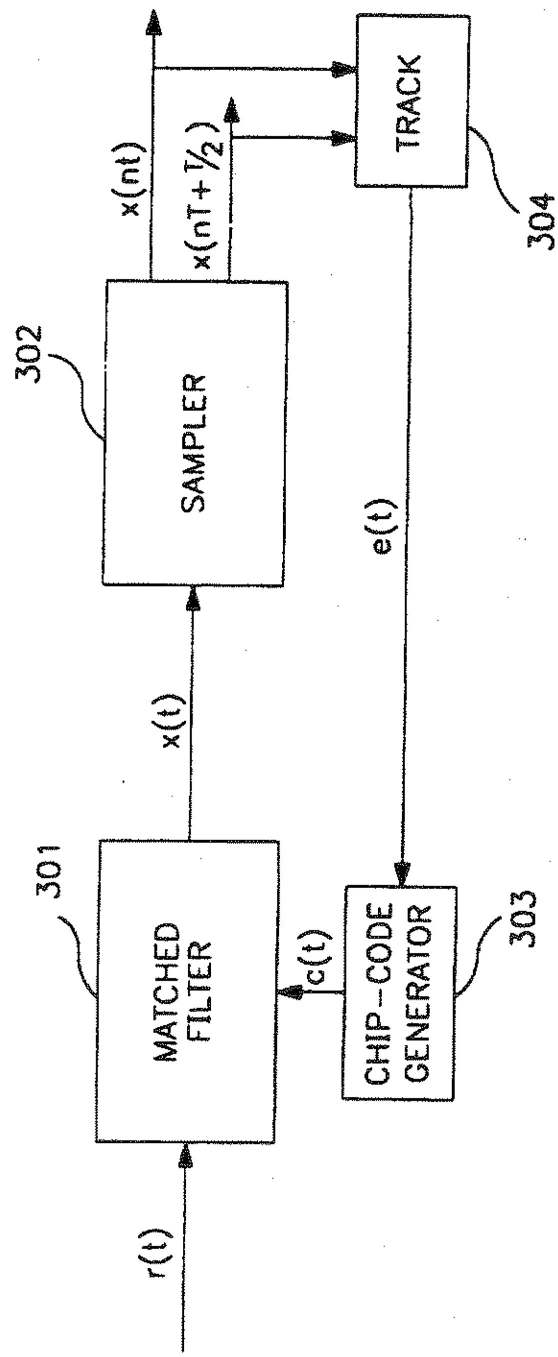
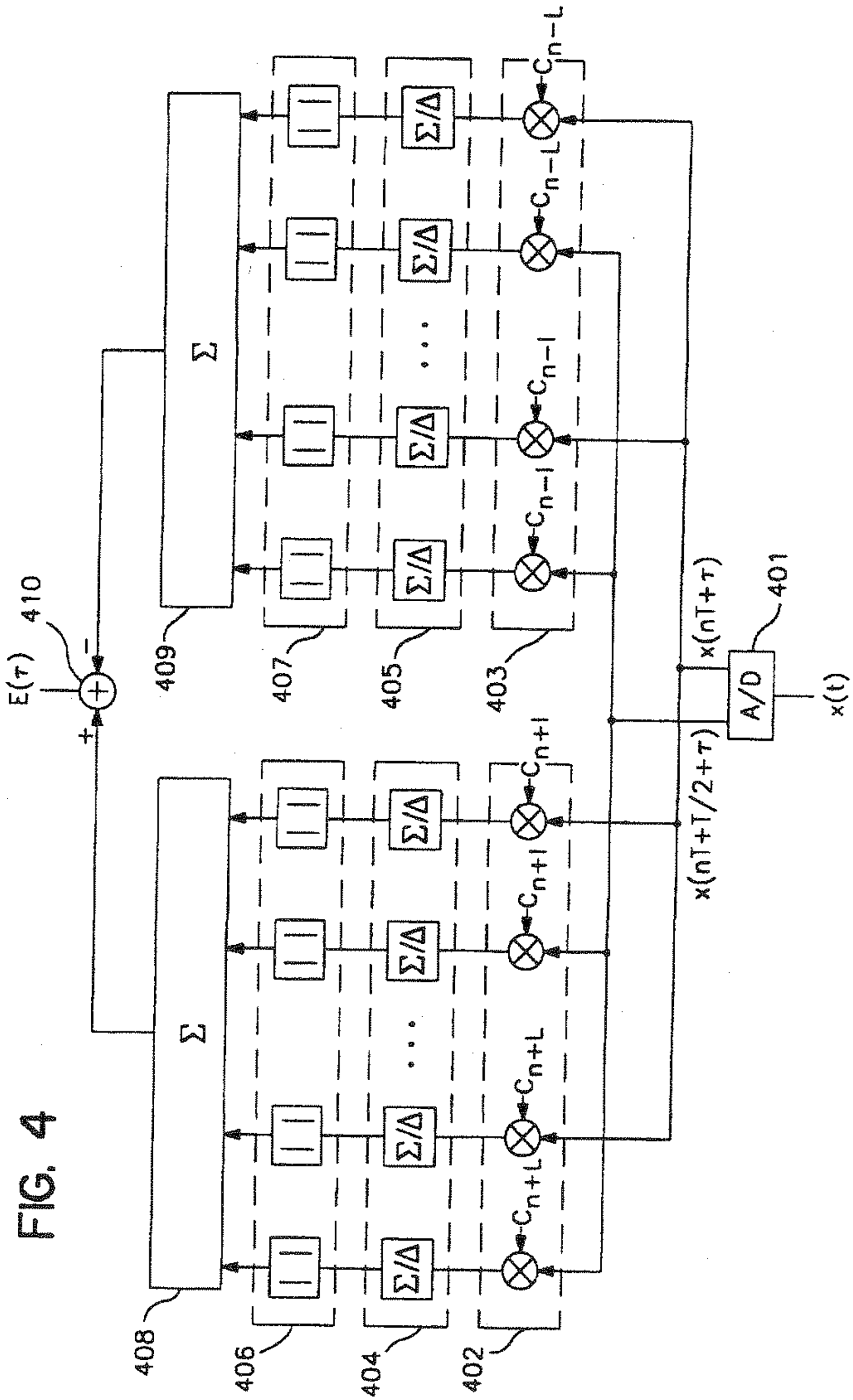

r(t)
MATCHED FILTER
301
x(t)
SAMPLER
302
x(nt)
x(nT+T/2)
TRACK
304
e(t)
CHIP-CODE GENERATOR
303
c(t)

FIG. 3c



E(τ)
410
+
−
409
408
407
406
405
404
403
402
401
Σ
Σ
Σ/Δ
C_{n-L}
C_{n-I}
C_{n+I}
C_{n+L}
x(nT+τ)
x(nT+T/2+τ)
A/D
x(t)

FIG. 4

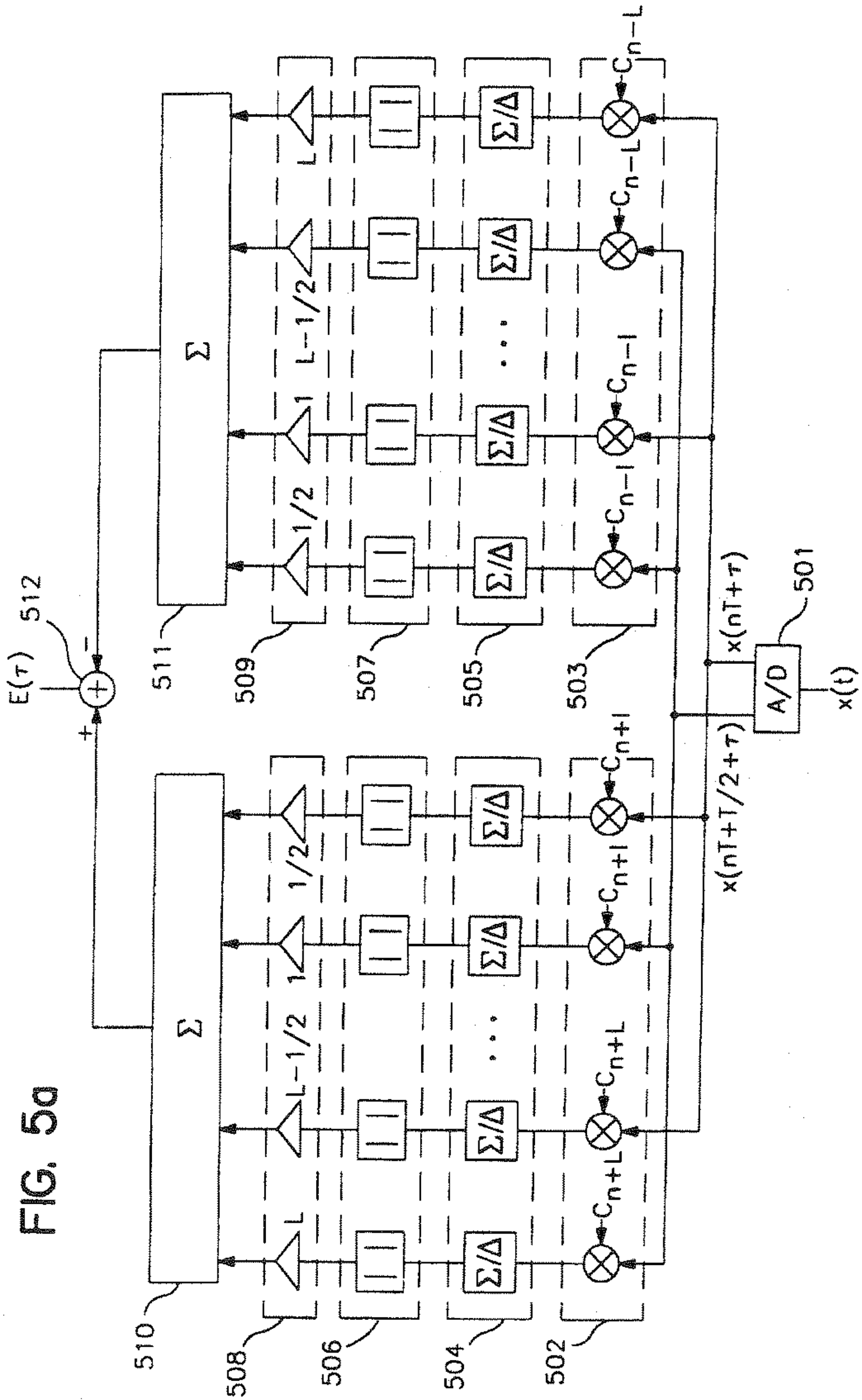
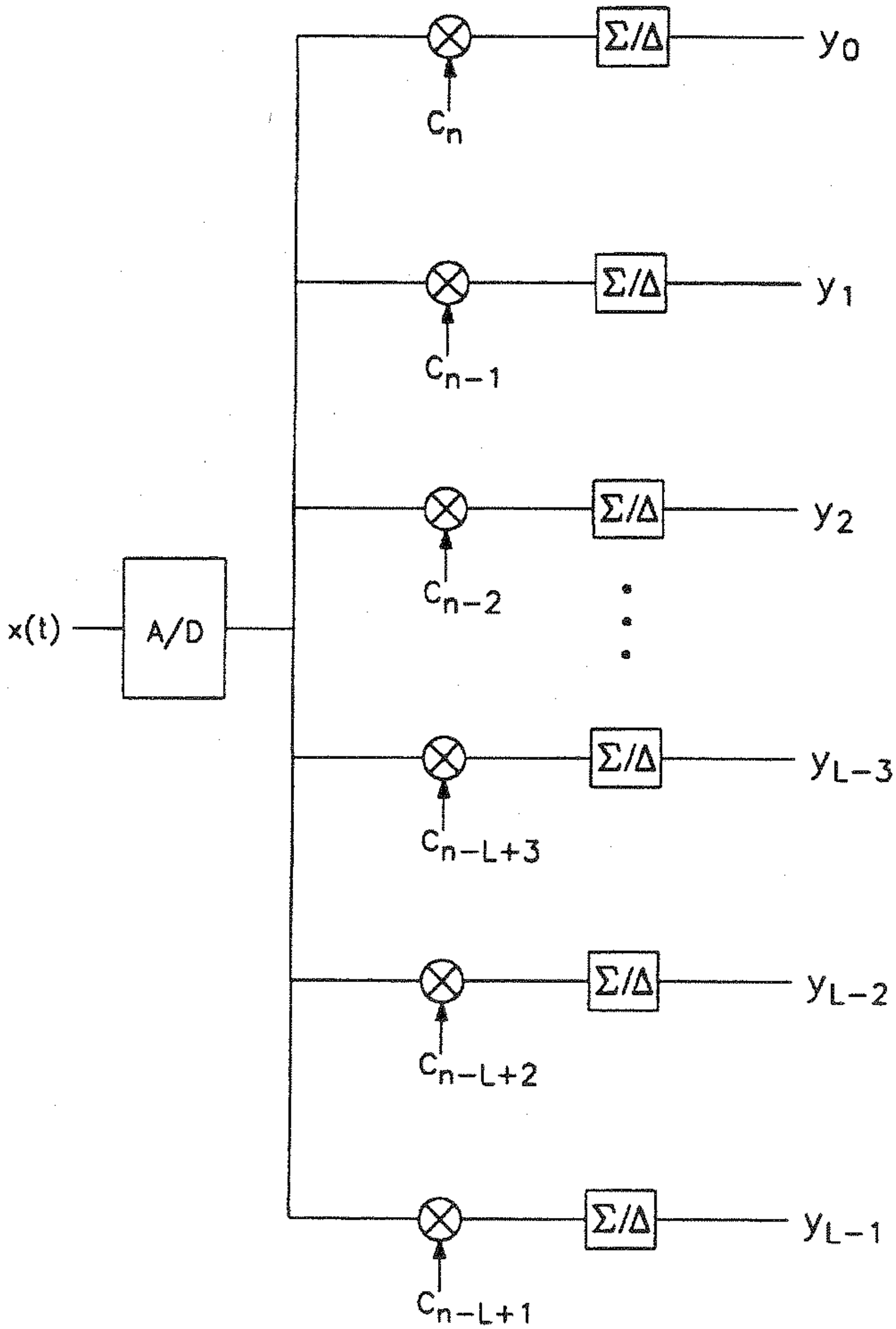

E(τ)
512
+
-
511
510
509
508
507
506
505
504
503
502
501
Σ
Σ/Δ
L
L-1/2
1
1/2
C_{n-L}
C_{n-I}
C_{n+I}
C_{n+L}
A/D
x(t)
x(nT+τ)
x(nT+T/2+τ)

FIG. 5a

FIG. 5b



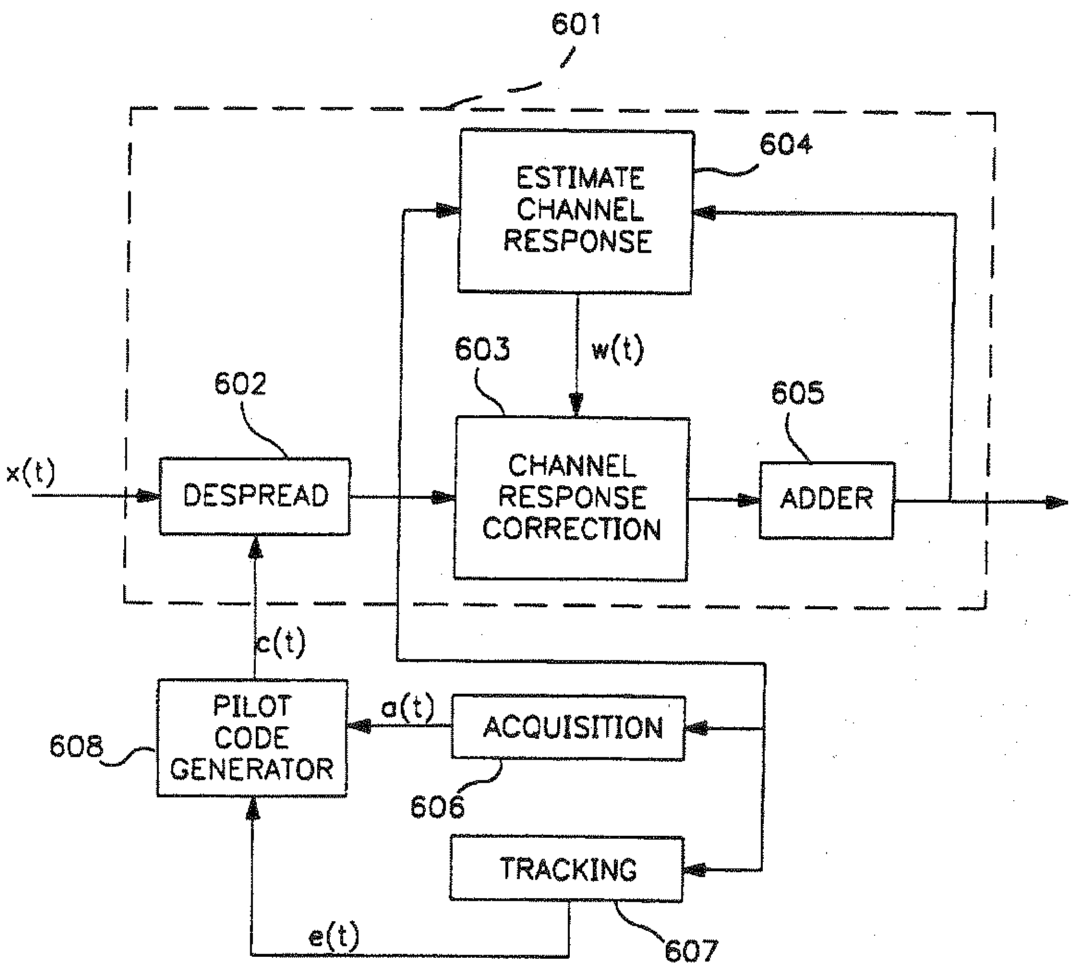
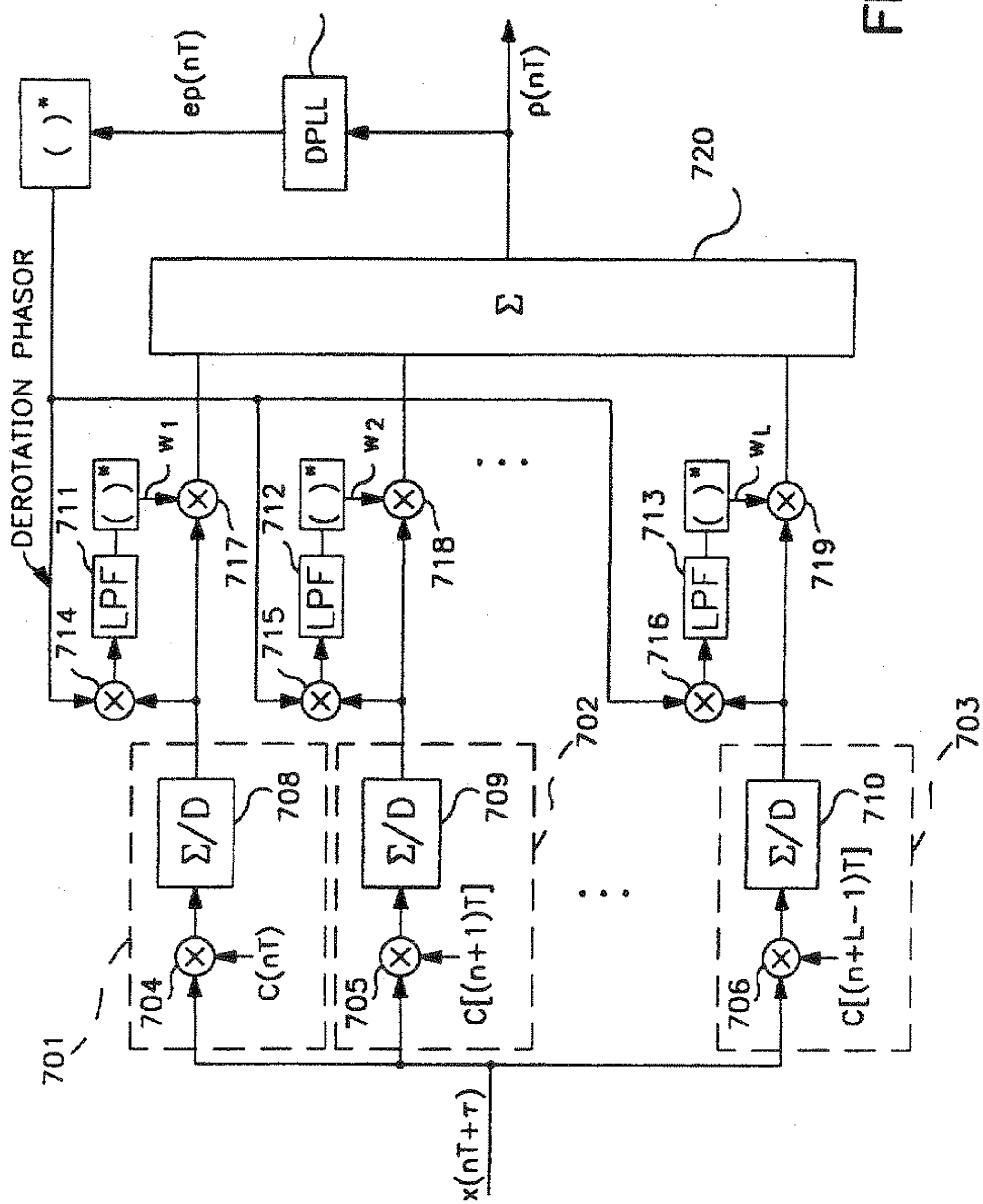
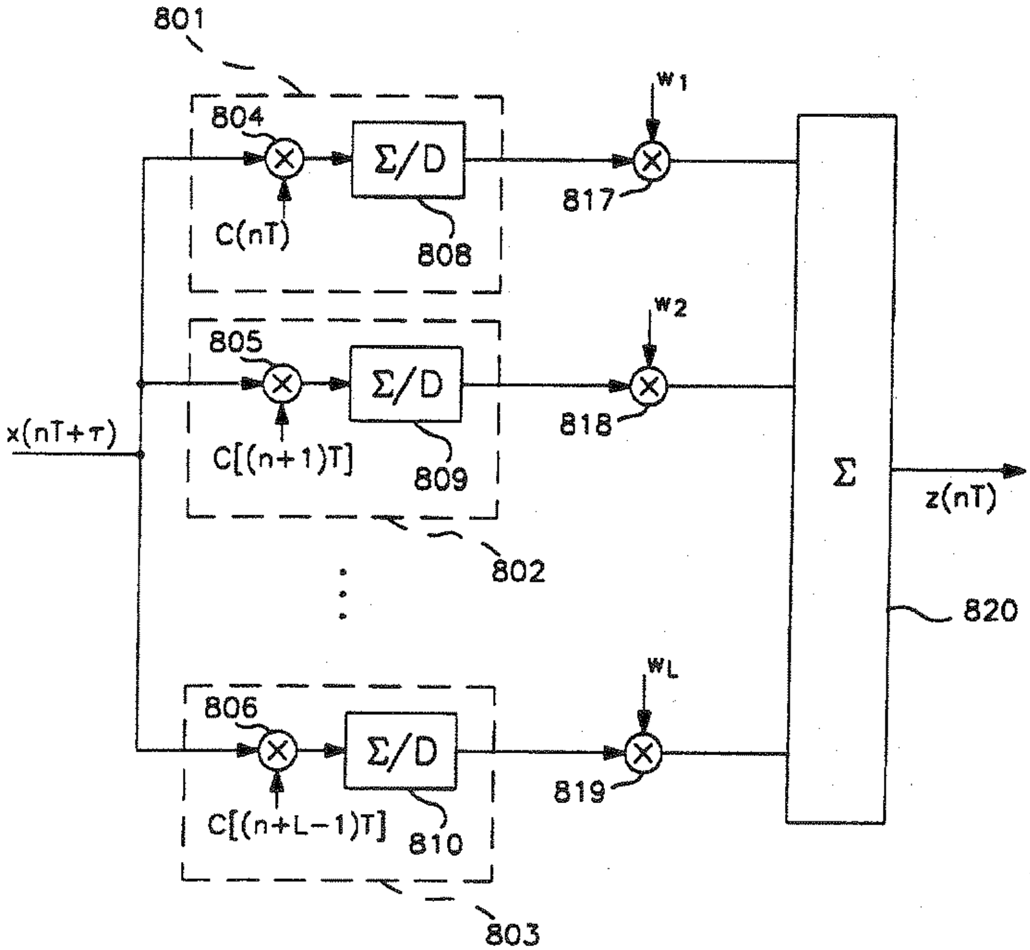

601
604
ESTIMATE CHANNEL RESPONSE
603
w(t)
602
605
x(t)
DESPREAD
CHANNEL RESPONSE CORRECTION
ADDER
c(t)
PILOT CODE GENERATOR
a(t)
ACQUISITION
608
606
TRACKING
e(t)
607

FIG. 6



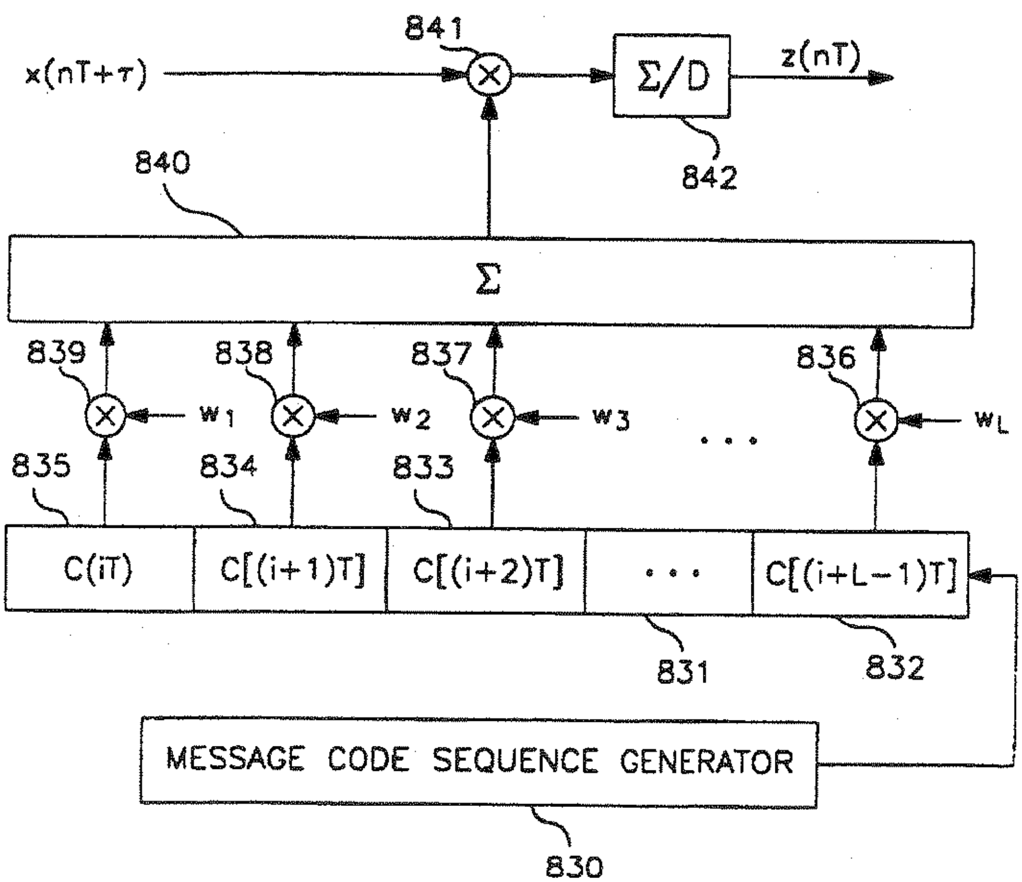
DEROTATION PHASOR
( )*
ep(nT)
DPLL
721
p(nT)
720
Σ
711
LPF
( )*
w1
714
717
712
715
718
w2
713
716
719
wL
Σ/D
708
709
710
701
702
703
704
705
706
C(nT)
C[(n+1)T]
C[(n+L−1)T]
x(nT+τ)

FIG. 7



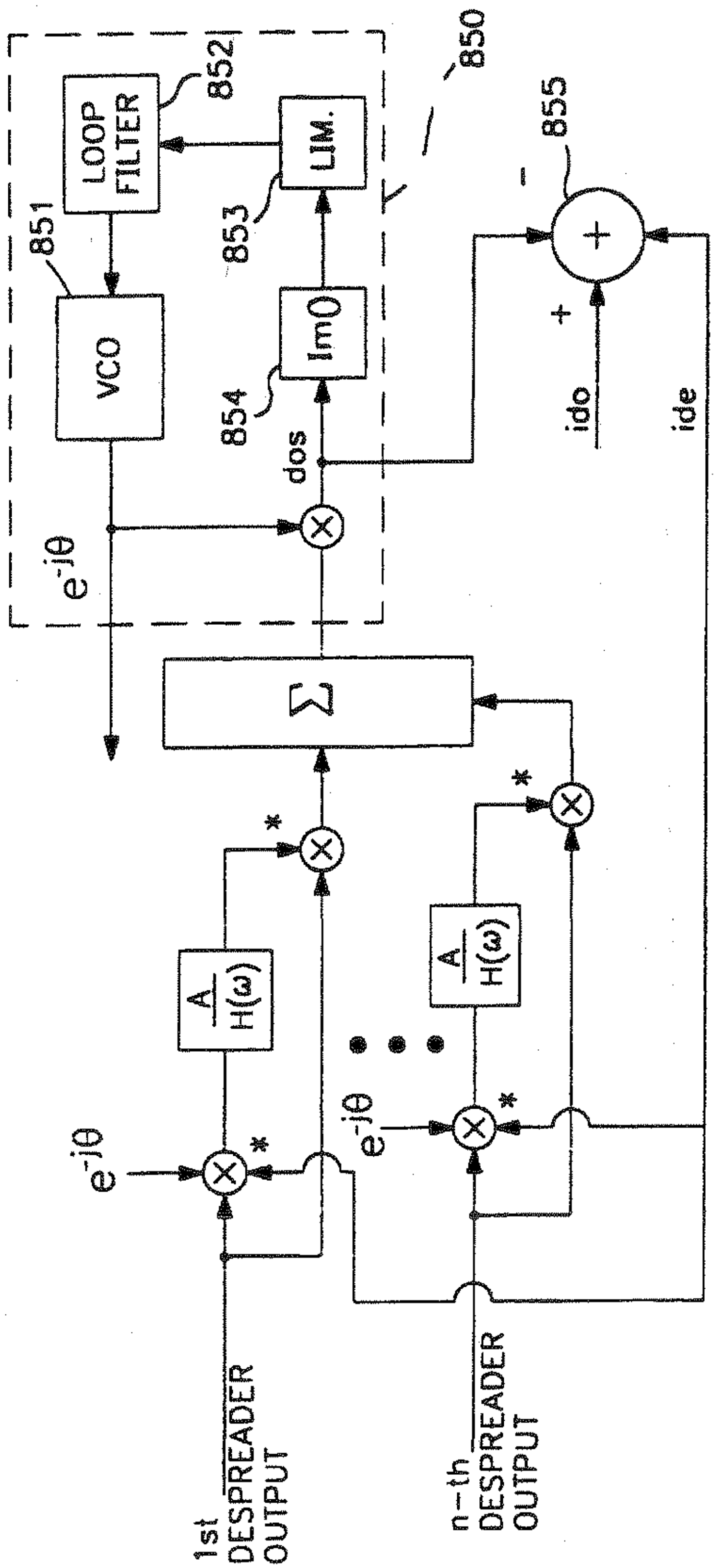
801
804
Σ/D
C(nT)
808
w1
817
805
Σ/D
C[(n+1)T]
809
w2
818
x(nT+τ)
802
Σ
z(nT)
820
806
Σ/D
C[(n+L−1)T]
810
wL
819
803

FIG. 8a



841
x(nT+τ)
Σ/D
z(nT)
840
842
Σ
839
838
837
836
w1
w2
w3
wL
. . .
835
834
833
C(iT)
C[(i+1)T]
C[(i+2)T]
. . .
C[(i+L−1)T]
831
832
MESSAGE CODE SEQUENCE GENERATOR
830

FIG. 8b



850
851
852
853
854
855
LOOP FILTER
VCO
LIM.
Im()
dos
ido
ide
+
-
$e^{-j\theta}$
Σ
$\frac{A}{H(\omega)}$
*
1st DESPREADER OUTPUT
n-th DESPREADER OUTPUT

FIG. 8c

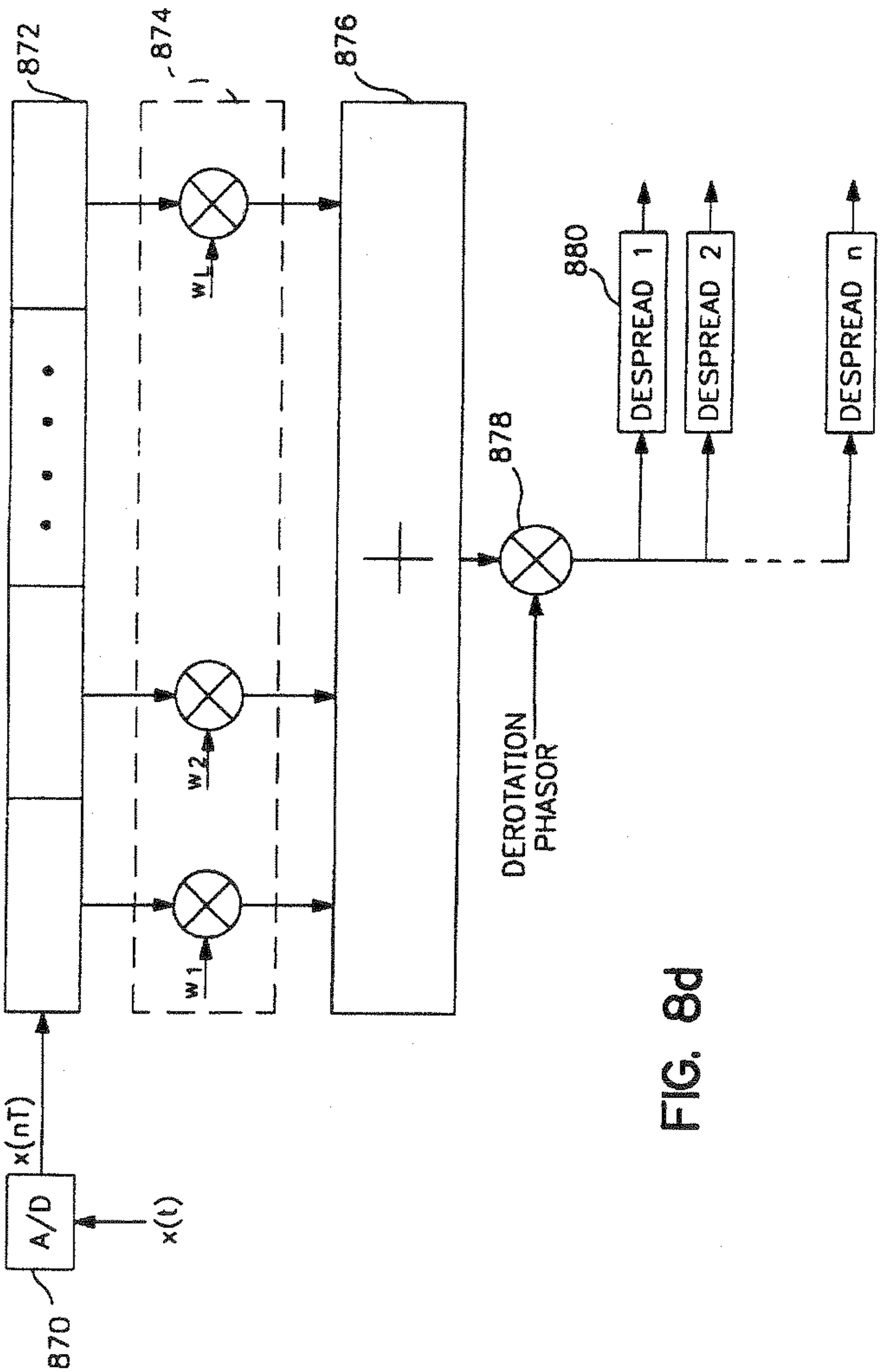
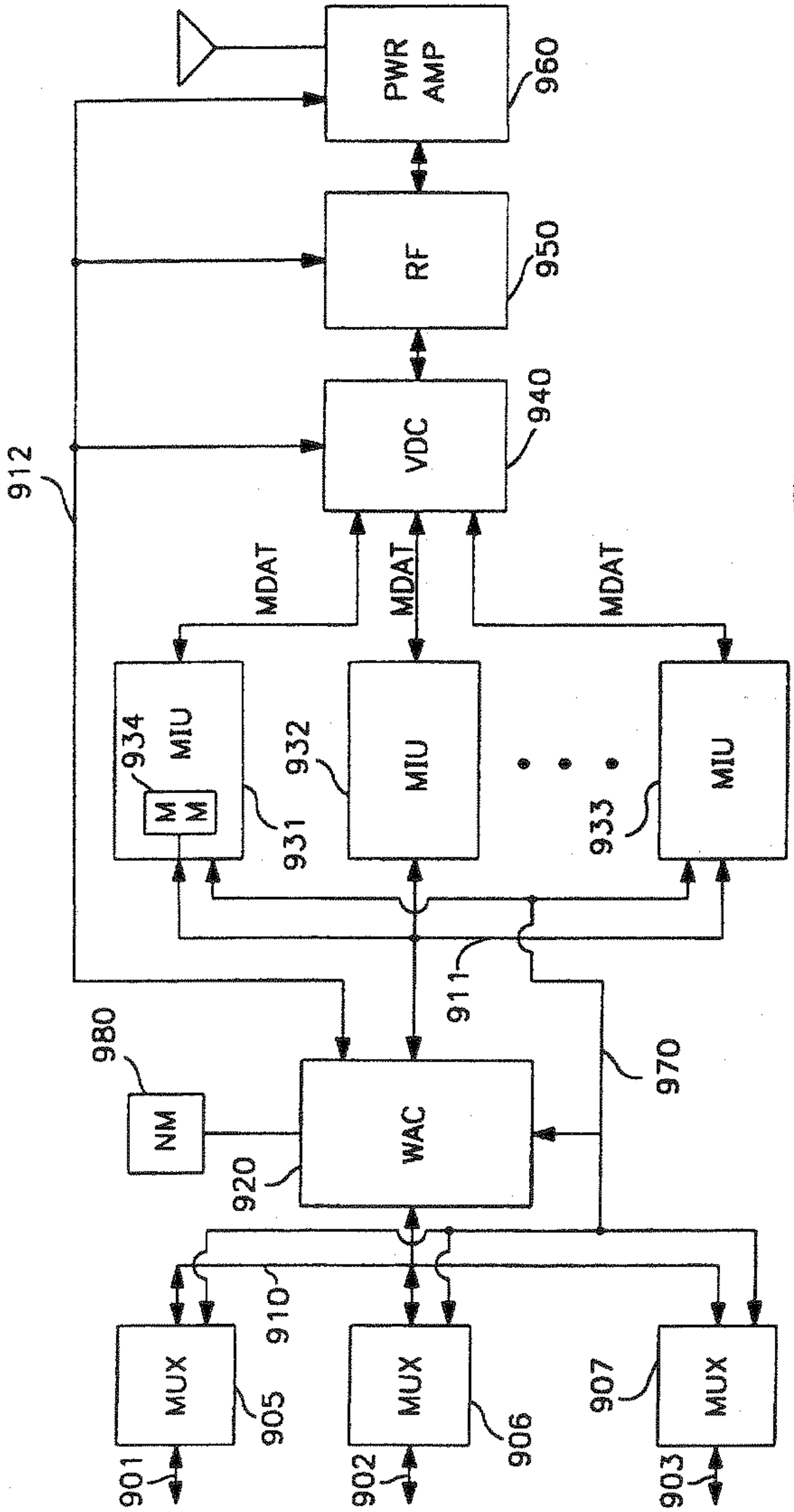

872
874
876
880
DESPREAD 1
DESPREAD 2
DESPREAD n
878
DEROTATION PHASOR
W L
W 2
W 1
x(nT)
A/D
x(t)
870

FIG. 8d



PWR AMP
960
RF
950
VDC
940
912
MDAT
MDAT
MDAT
934
MIU
M M
931
932
MIU
933
MIU
911
980
NM
920
WAC
970
910
MUX
905
MUX
906
907
MUX
901
902
903

FIG. 9

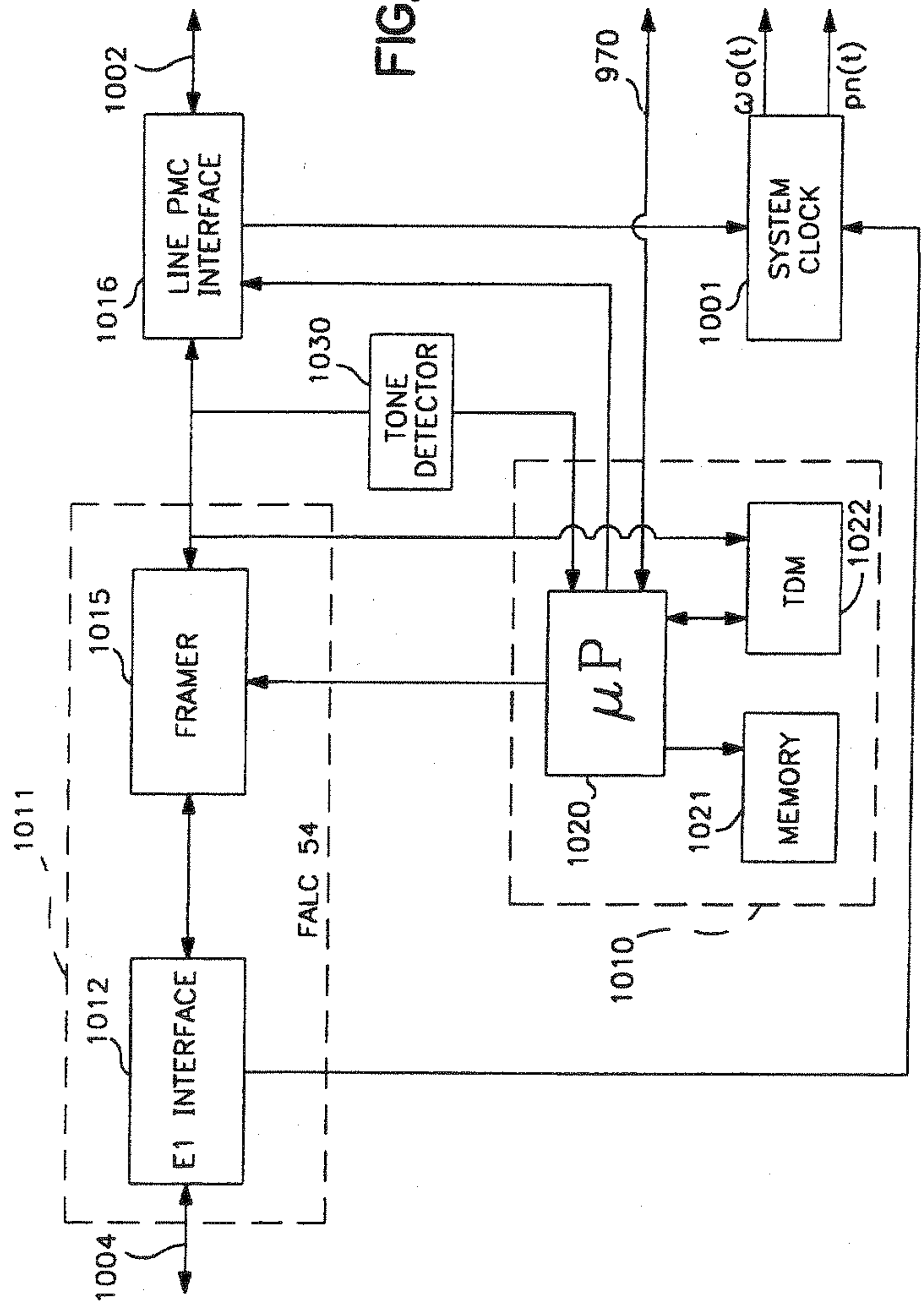

1002
LINE PMC INTERFACE
1016
970
ωo(t)
pn(t)
SYSTEM CLOCK
1001
TONE DETECTOR
1030
TDM
1022
μP
1020
MEMORY
1021
1010
FRAMER
1015
FALC 54
1011
E1 INTERFACE
1012
1004

FIG. 10

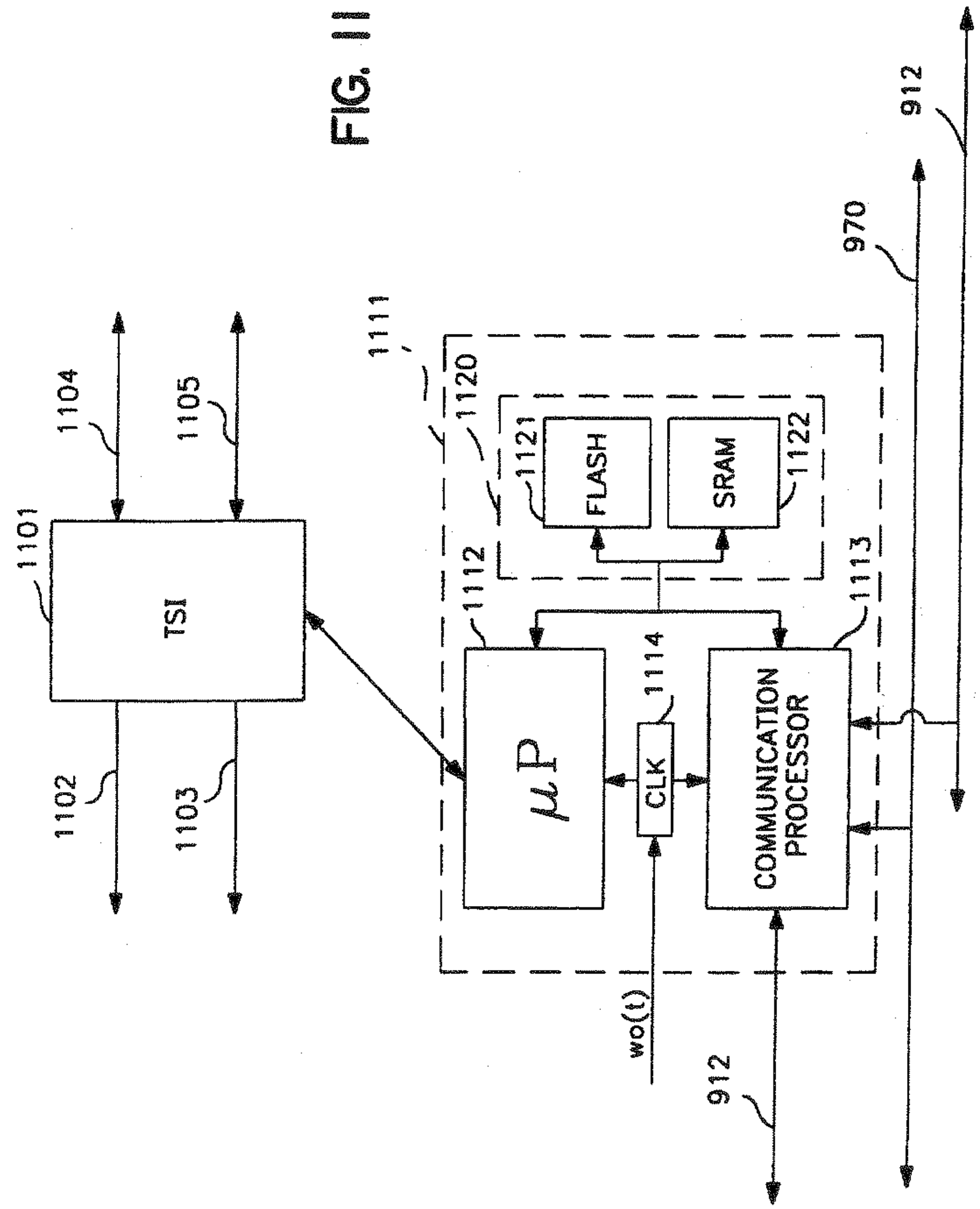

1101
TSI
1104
1105
1102
1103
1111
1120
1121
FLASH
SRAM
1122
1112
μP
1114
CLK
1113
COMMUNICATION
PROCESSOR
wo(t)
912
970
912

FIG. 11

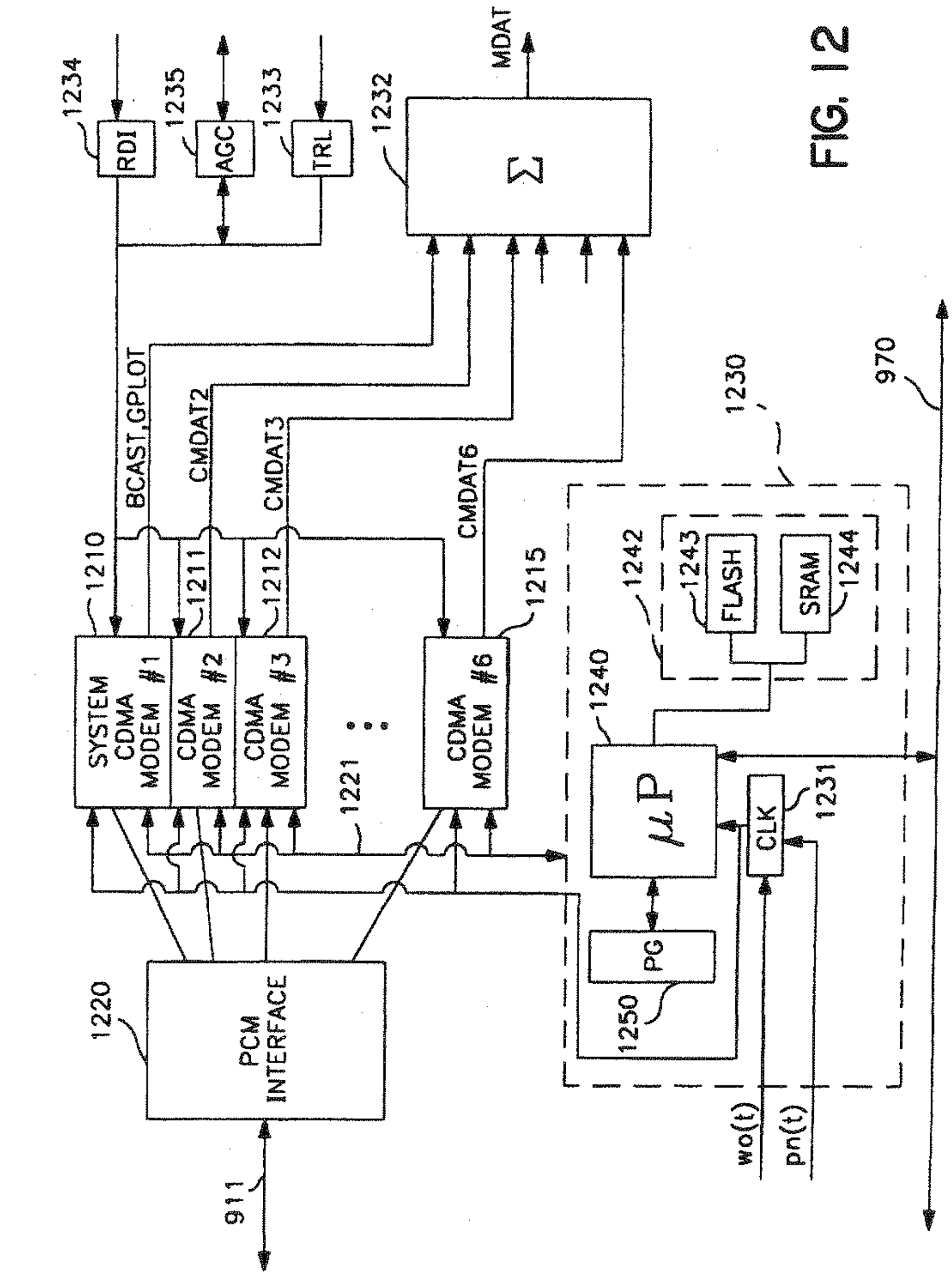

1234
RDI
1235
AGC
1233
TRL
1232
Σ
MDAT
BCAST,GPLOT
CMDAT2
CMDAT3
CMDAT6
1210
1211
1212
1215
SYSTEM CDMA MODEM #1
CDMA MODEM #2
CDMA MODEM #3
CDMA MODEM #6
1221
1220
PCM INTERFACE
911
1230
1242
1243
FLASH
SRAM
1244
1240
μP
CLK
1231
PG
1250
wo(t)
pn(t)
970

FIG. 12

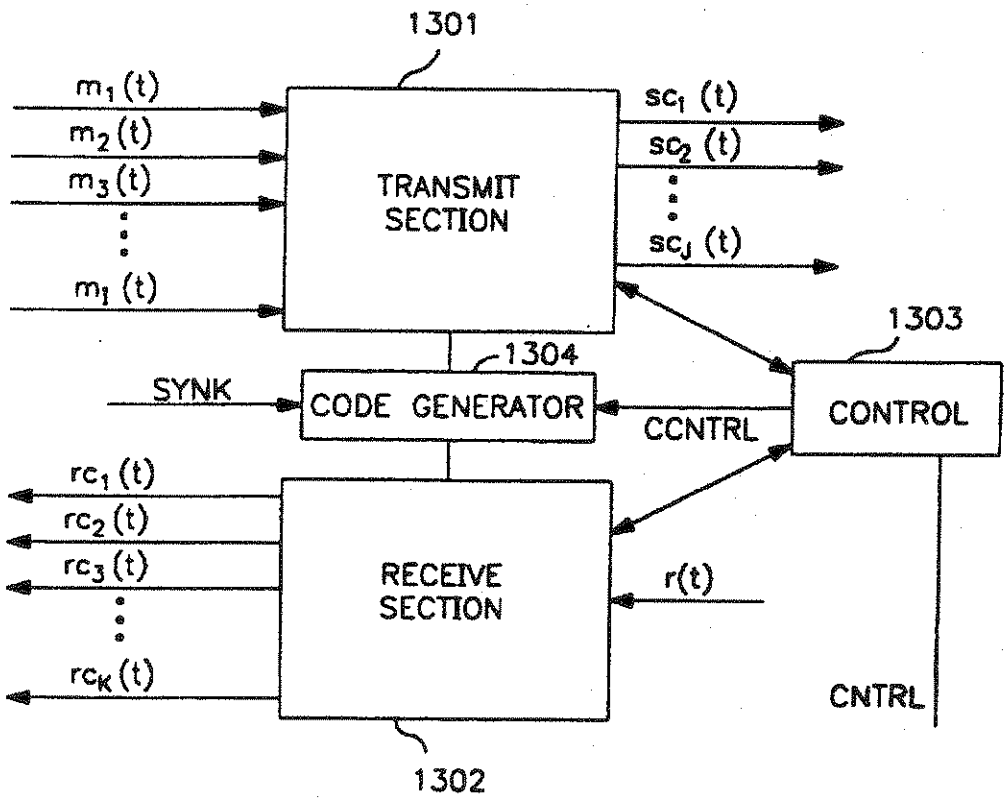

1301
m_1 (t)
m_2 (t)
m_3 (t)
m_I (t)
TRANSMIT SECTION
sc_1 (t)
sc_2 (t)
sc_J (t)
1303
1304
SYNK
CODE GENERATOR
CCNTRL
CONTROL
rc_1 (t)
rc_2 (t)
rc_3 (t)
rc_K (t)
RECEIVE SECTION
r(t)
CNTRL
1302

FIG. 13

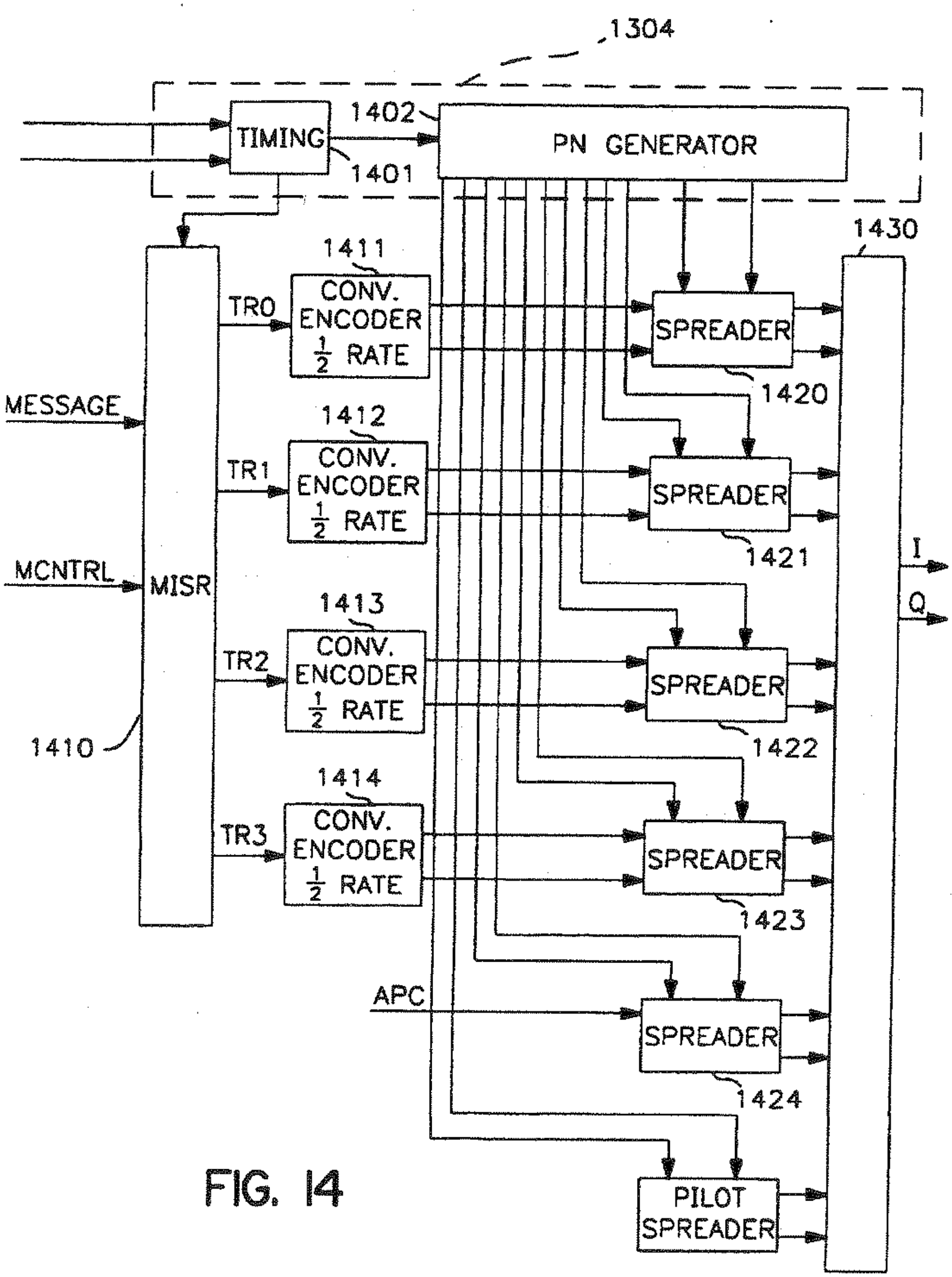
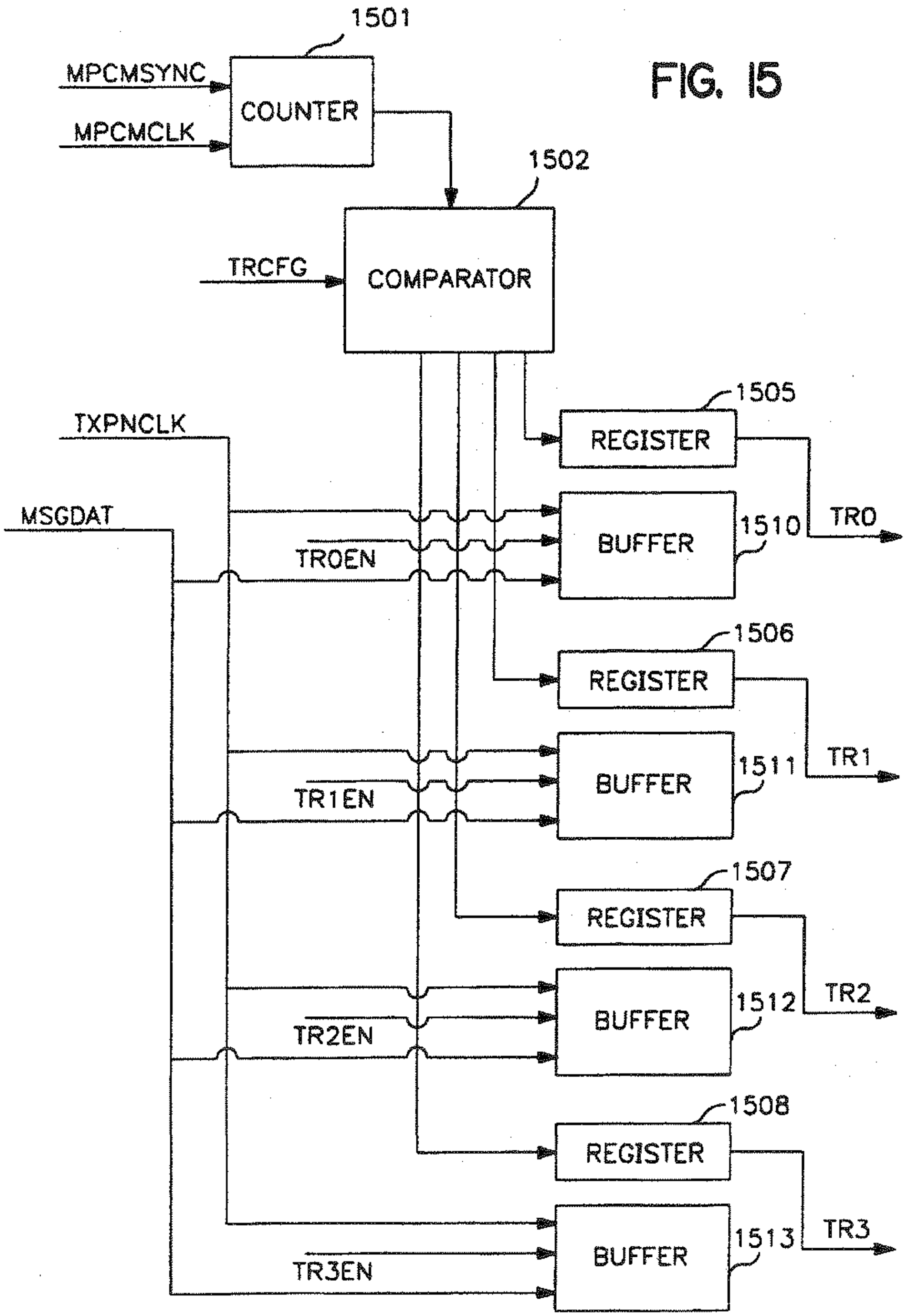

1304
TIMING
1402
PN GENERATOR
1401
1430
1411
CONV. ENCODER ½ RATE
TR0
SPREADER
1420
MESSAGE
1412
TR1
CONV. ENCODER ½ RATE
SPREADER
1421
I
Q
MCNTRL
MISR
1413
TR2
CONV. ENCODER ½ RATE
SPREADER
1422
1410
1414
TR3
CONV. ENCODER ½ RATE
SPREADER
1423
APC
SPREADER
1424
PILOT SPREADER

FIG. 14

FIG. 15


1501
MPCMSYNC
MPCMCLK
COUNTER
1502
TRCFG
COMPARATOR
TXPNCLK
MSGDAT
1505
REGISTER
BUFFER
1510
TR0
TR0EN
1506
REGISTER
BUFFER
1511
TR1
TR1EN
1507
REGISTER
BUFFER
1512
TR2
TR2EN
1508
REGISTER
BUFFER
1513
TR3
TR3EN

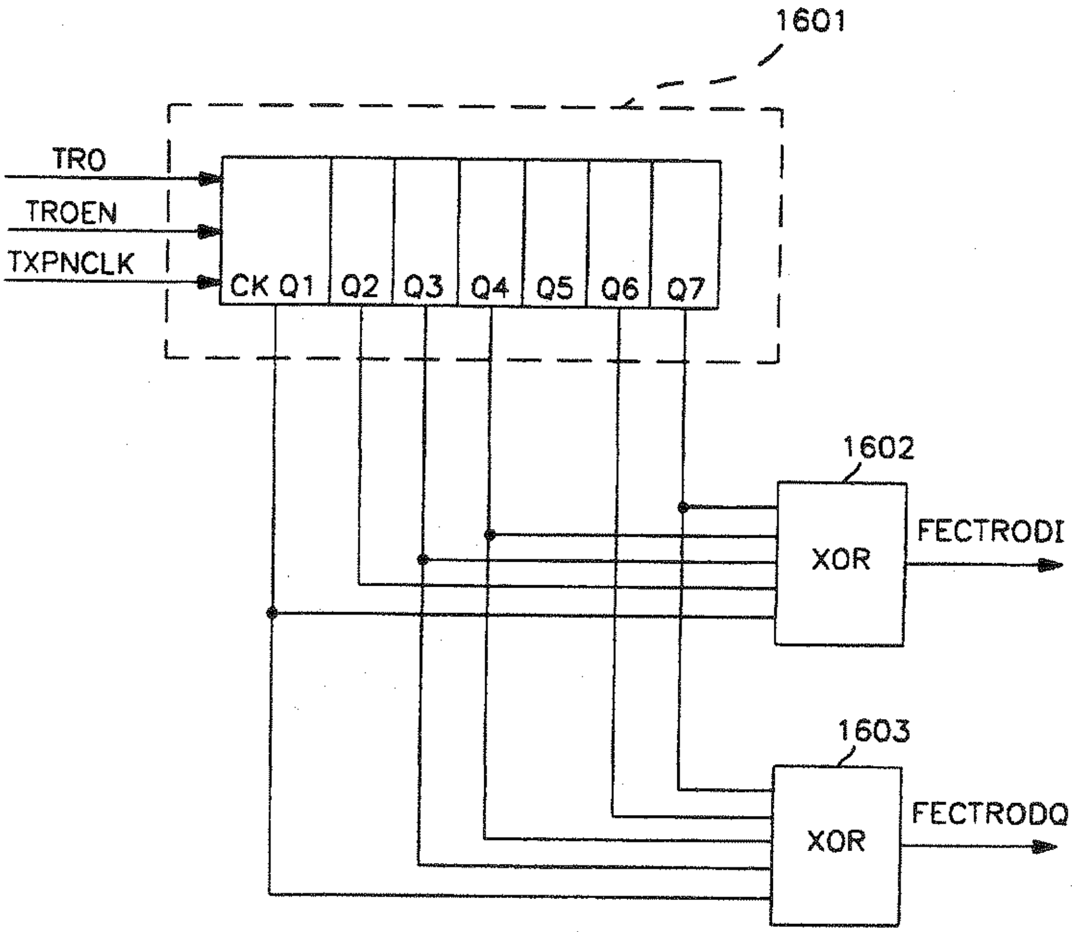
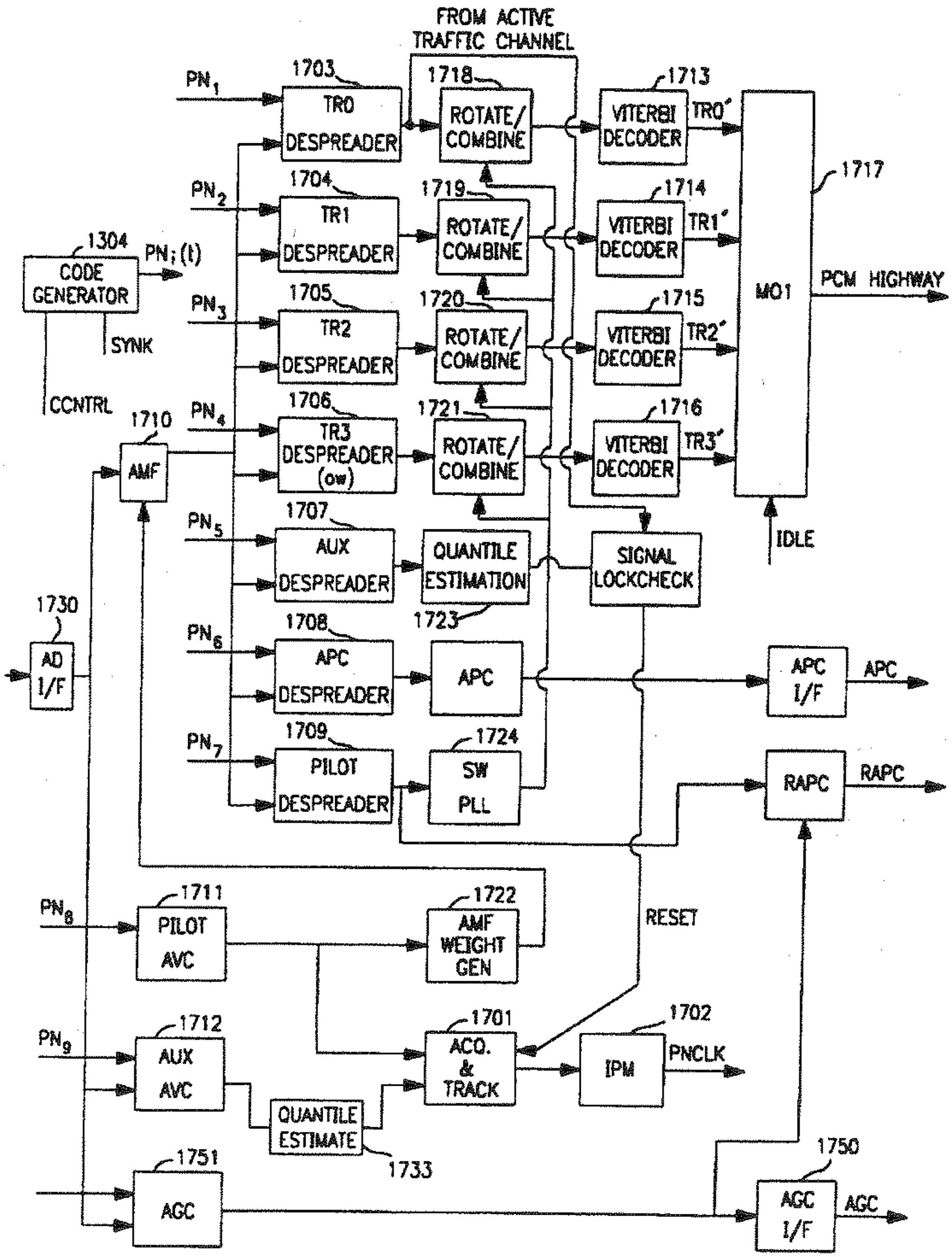
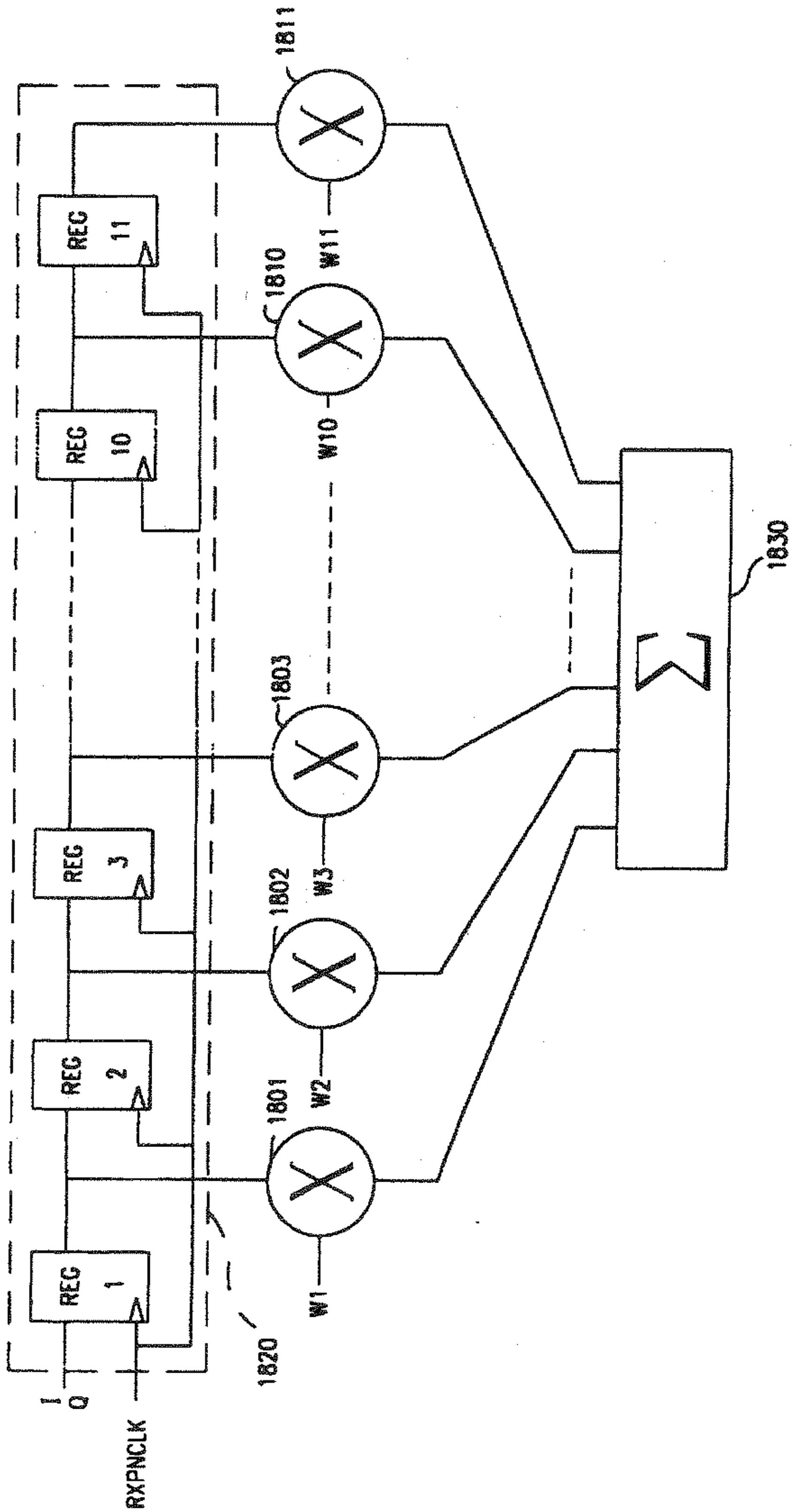

1601
TRO
TROEN
TXPNCLK
CK Q1
Q2
Q3
Q4
Q5
Q6
Q7
1602
XOR
FECTRODI
1603
XOR
FECTRODQ

FIG. 16



FROM ACTIVE TRAFFIC CHANNEL
PN1
1703
TR0 DESPREADER
1718
ROTATE/ COMBINE
1713
VITERBI DECODER
TR0'
1717
PN2
1704
TR1 DESPREADER
1719
ROTATE/ COMBINE
1714
VITERBI DECODER
TR1'
1304
CODE GENERATOR
PNi (t)
SYNK
CCNTRL
PN3
1705
TR2 DESPREADER
1720
ROTATE/ COMBINE
1715
VITERBI DECODER
TR2'
MO1
PCM HIGHWAY
1710
AMF
PN4
1706
TR3 DESPREADER (ow)
1721
ROTATE/ COMBINE
1716
VITERBI DECODER
TR3'
IDLE
PN5
1707
AUX DESPREADER
QUANTILE ESTIMATION
1723
SIGNAL LOCKCHECK
1730
AD I/F
PN6
1708
APC DESPREADER
APC
APC I/F
APC
PN7
1709
PILOT DESPREADER
1724
SW PLL
RAPC
RAPC
RESET
PN8
1711
PILOT AVC
1722
AMF WEIGHT GEN
PN9
1712
AUX AVC
1701
ACQ. & TRACK
1702
IPM
PNCLK
QUANTILE ESTIMATE
1733
1751
AGC
1750
AGC I/F
AGC

FIG. 17



1811
1810
1803
1802
1801
REG 11
REG 10
REG 3
REG 2
REG 1
W11
W10
W3
W2
W1
1830
1820
I
Q
RXPNCLK

FIG. 18

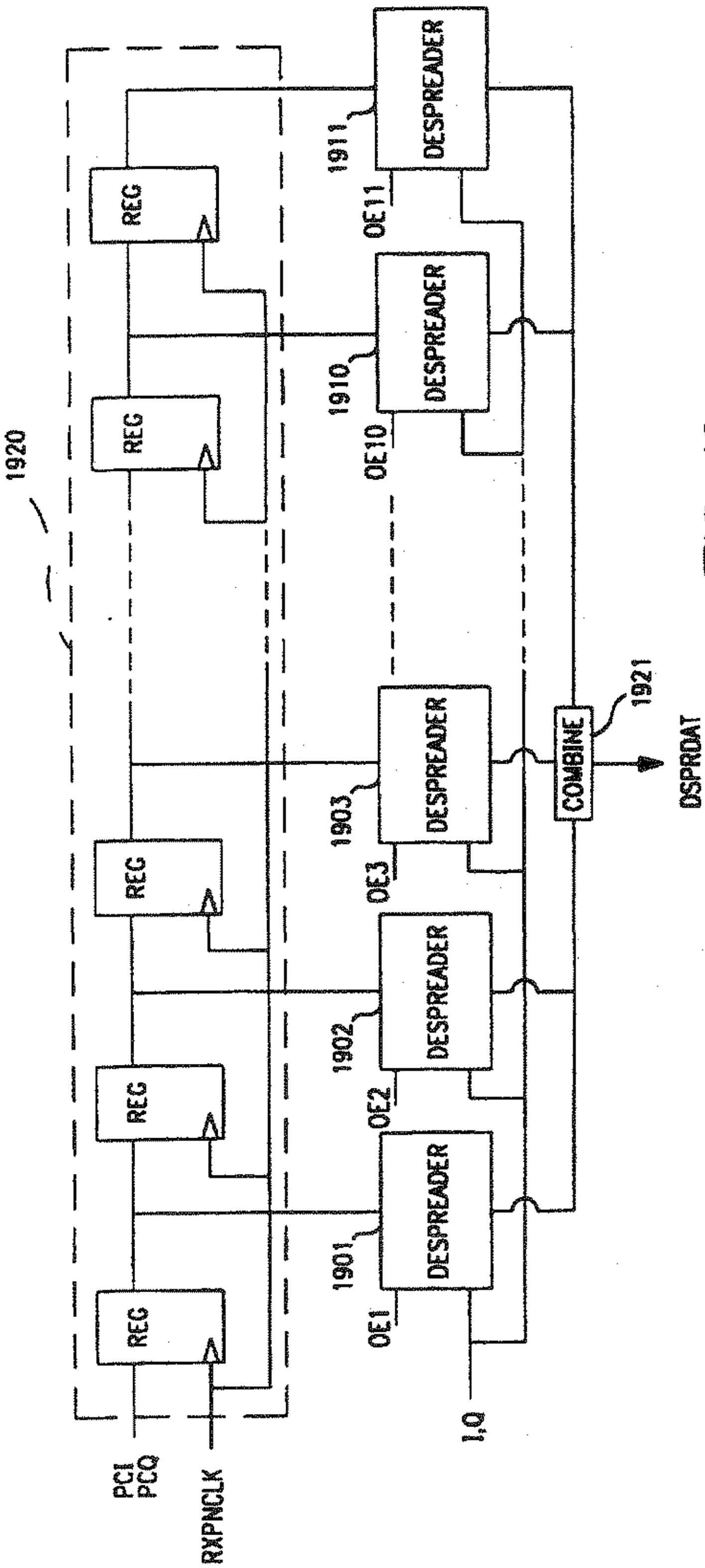

1920
REG
REG
REG
REG
REG
DESPREADER
DESPREADER
DESPREADER
DESPREADER
DESPREADER
1911
1910
1903
1902
1901
OE11
OE10
OE3
OE2
OE1
COMBINE
1921
DSPRDAT
PCI
PCQ
RXPNCLK
I,Q

FIG. 19

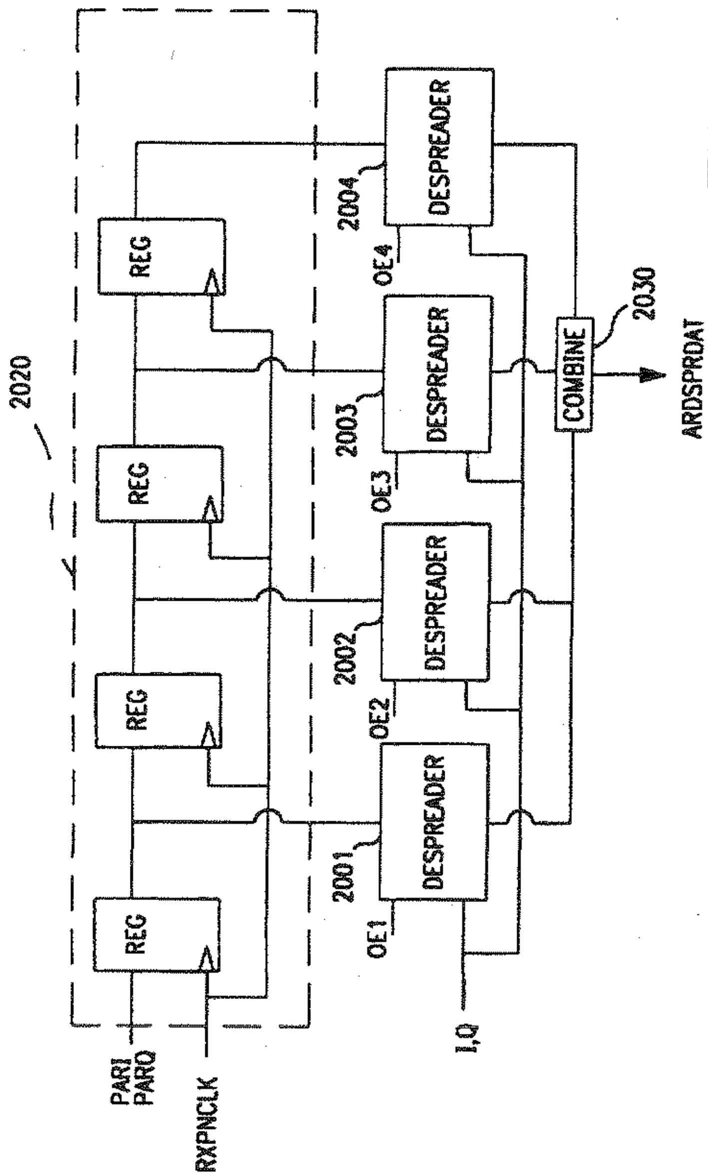
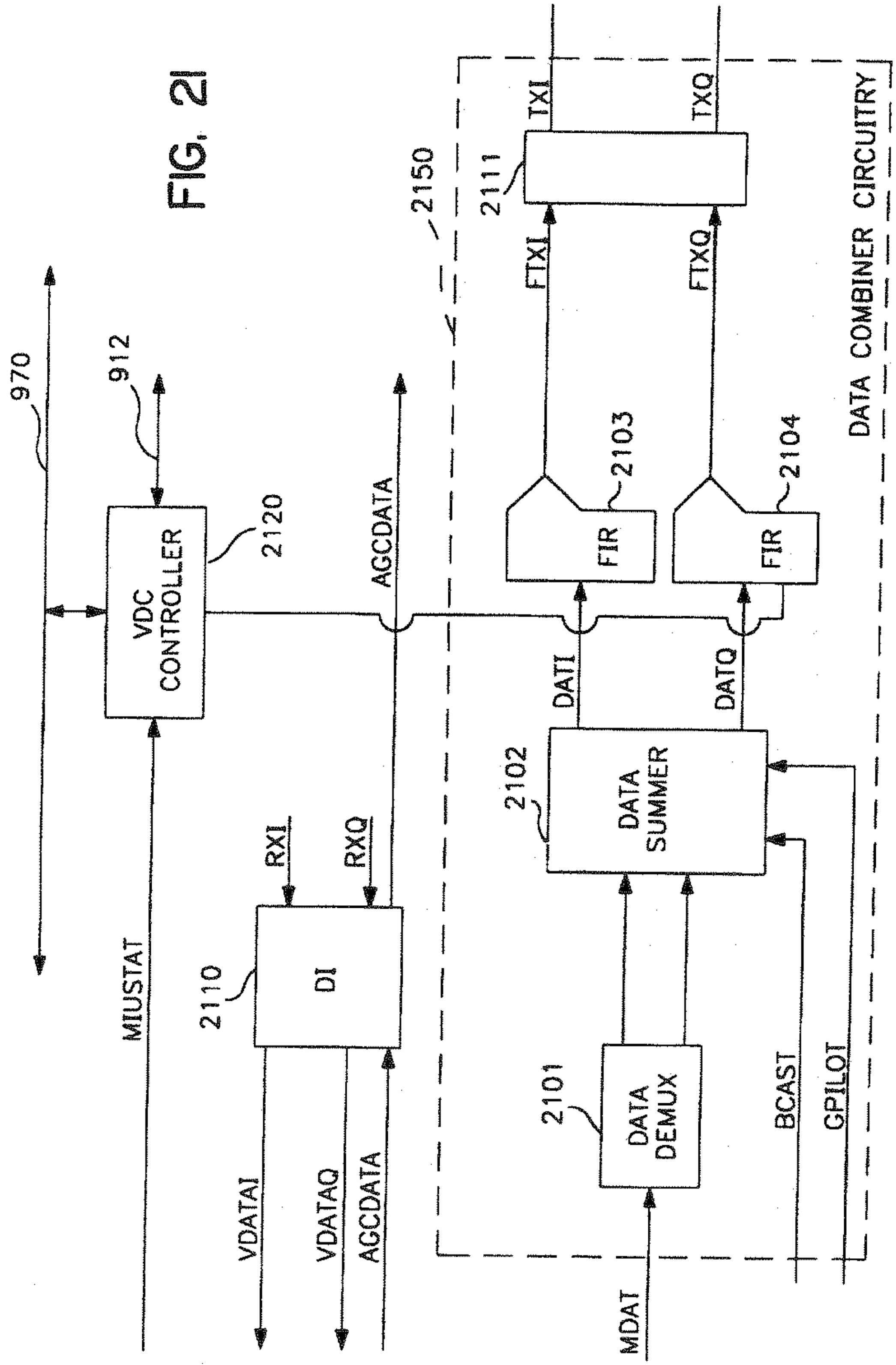

2020
REG
REG
REG
REG
DESPREADER
DESPREADER
DESPREADER
DESPREADER
2001
2002
2003
2004
OE1
OE2
OE3
OE4
COMBINE
2030
ARDSPRDAT
PARI
PARQ
RXPNCLK
I,Q

FIG. 20



970
912
VDC CONTROLLER
2120
MIUSTAT
AGCDATA
2150
2111
TXI
TXQ
FTXI
FTXQ
FIR
2103
FIR
2104
DATA COMBINER CIRCUITRY
DATI
DATQ
DATA SUMMER
2102
RXI
RXQ
DI
2110
VDATAI
VDATAQ
AGCDATA
DATA DEMUX
2101
BCAST
GPILOT
MDAT

FIG. 2I

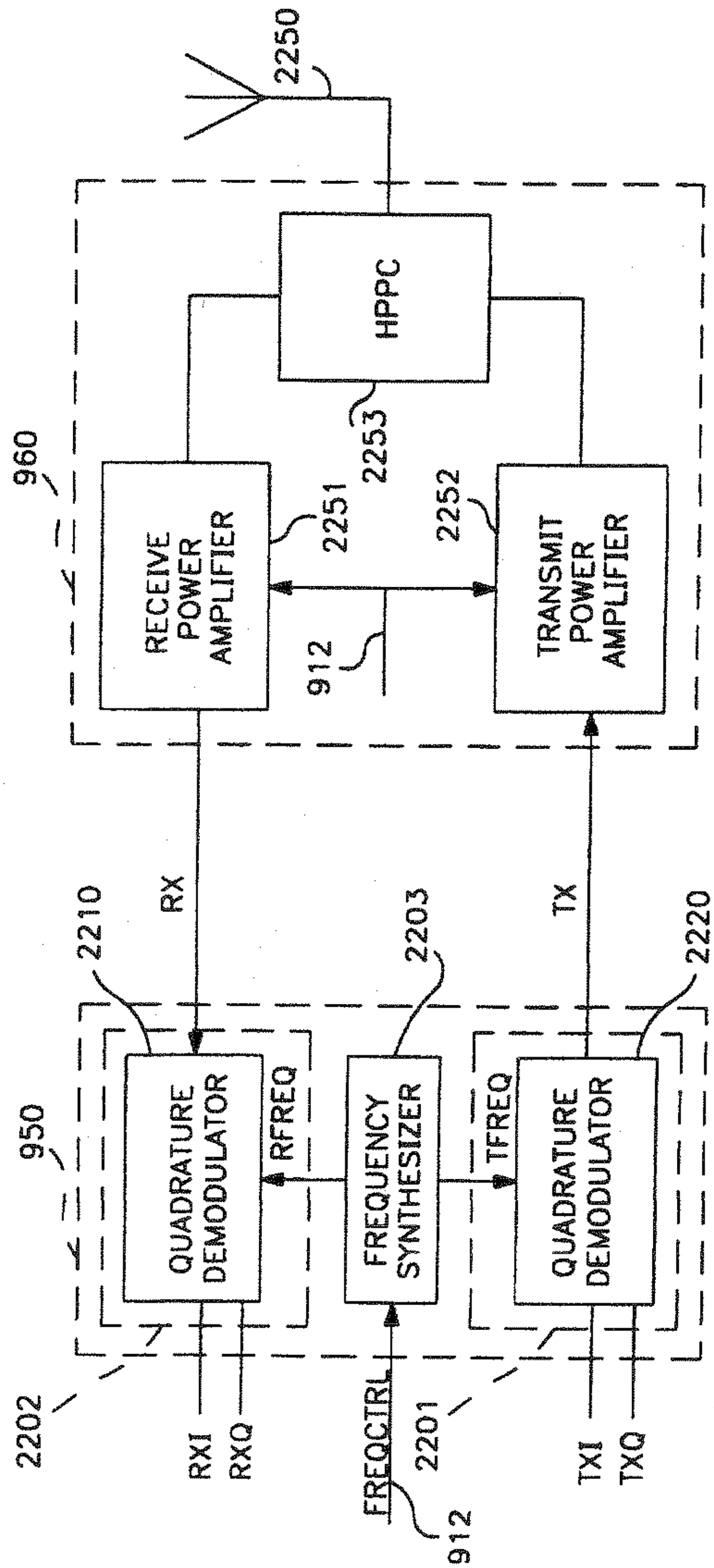
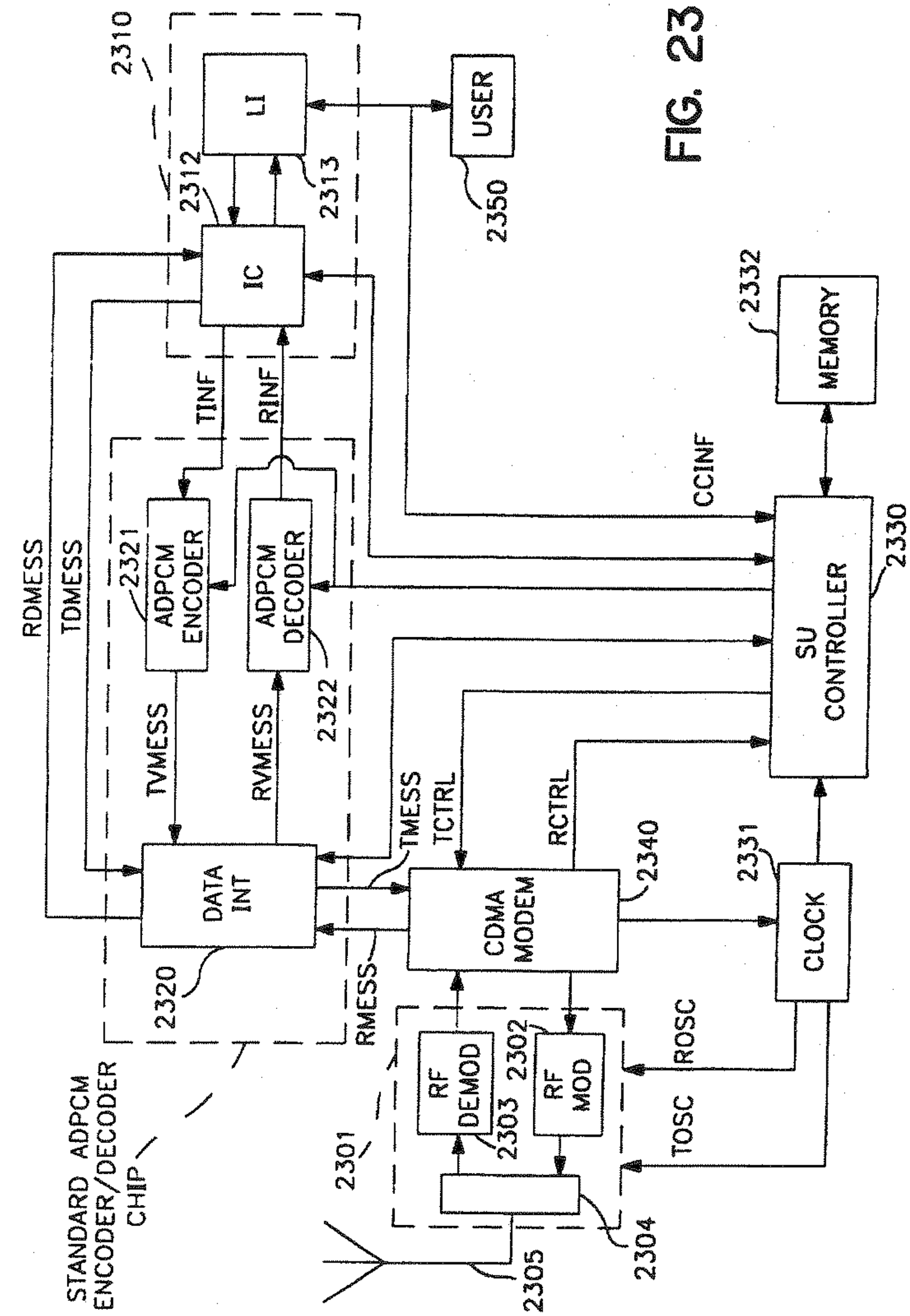

2250
960
HPPC
2253
RECEIVE POWER AMPLIFIER
2251
2252
TRANSMIT POWER AMPLIFIER
912
RX
TX
2210
2203
2220
950
QUADRATURE DEMODULATOR
RFREQ
FREQUENCY SYNTHESIZER
TFREQ
QUADRATURE DEMODULATOR
2202
RXI
RXQ
FREQCTRL
2201
912
TXI
TXQ

FIG. 22



2310
LI
2312
2313
USER
2350
IC
TINF
RINF
RDMESS
TDMESS
2321
ADPCM ENCODER
ADPCM DECODER
2322
TVMESS
RVMESS
TMESS
TCTRL
RCTRL
CCINF
MEMORY
2332
SU CONTROLLER
2330
DATA INT
2320
CDMA MODEM
2340
CLOCK
2331
RMESS
RF DEMOD
RF MOD
2302
2303
ROSC
TOSC
2301
2304
2305
STANDARD ADPCM ENCODER/DECODER CHIP

FIG. 23

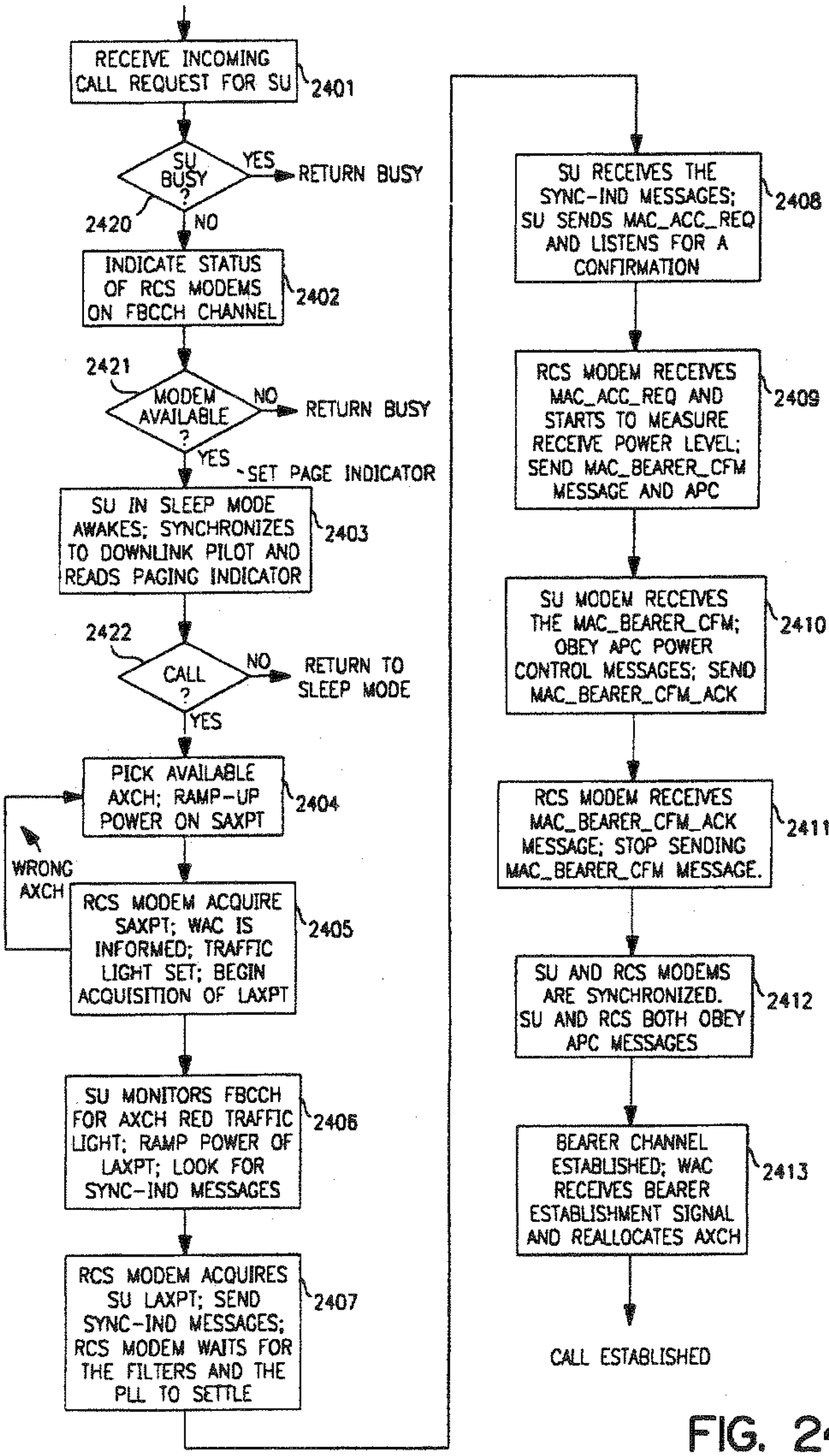

RECEIVE INCOMING CALL REQUEST FOR SU
2401
SU BUSY ?
YES
RETURN BUSY
2420
NO
INDICATE STATUS OF RCS MODEMS ON FBCCH CHANNEL
2402
2421
MODEM AVAILABLE ?
NO
RETURN BUSY
YES
SET PAGE INDICATOR
SU IN SLEEP MODE AWAKES; SYNCHRONIZES TO DOWNLINK PILOT AND READS PAGING INDICATOR
2403
2422
CALL ?
NO
RETURN TO SLEEP MODE
YES
PICK AVAILABLE AXCH; RAMP-UP POWER ON SAXPT
2404
WRONG AXCH
RCS MODEM ACQUIRE SAXPT; WAC IS INFORMED; TRAFFIC LIGHT SET; BEGIN ACQUISITION OF LAXPT
2405
SU MONITORS FBCCH FOR AXCH RED TRAFFIC LIGHT; RAMP POWER OF LAXPT; LOOK FOR SYNC-IND MESSAGES
2406
RCS MODEM ACQUIRES SU LAXPT; SEND SYNC-IND MESSAGES; RCS MODEM WAITS FOR THE FILTERS AND THE PLL TO SETTLE
2407
SU RECEIVES THE SYNC-IND MESSAGES; SU SENDS MAC_ACC_REQ AND LISTENS FOR A CONFIRMATION
2408
RCS MODEM RECEIVES MAC_ACC_REQ AND STARTS TO MEASURE RECEIVE POWER LEVEL; SEND MAC_BEARER_CFM MESSAGE AND APC
2409
SU MODEM RECEIVES THE MAC_BEARER_CFM; OBEY APC POWER CONTROL MESSAGES; SEND MAC_BEARER_CFM_ACK
2410
RCS MODEM RECEIVES MAC_BEARER_CFM_ACK MESSAGE; STOP SENDING MAC_BEARER_CFM MESSAGE.
2411
SU AND RCS MODEMS ARE SYNCHRONIZED. SU AND RCS BOTH OBEY APC MESSAGES
2412
BEARER CHANNEL ESTABLISHED; WAC RECEIVES BEARER ESTABLISHMENT SIGNAL AND REALLOCATES AXCH
2413
CALL ESTABLISHED

FIG. 24

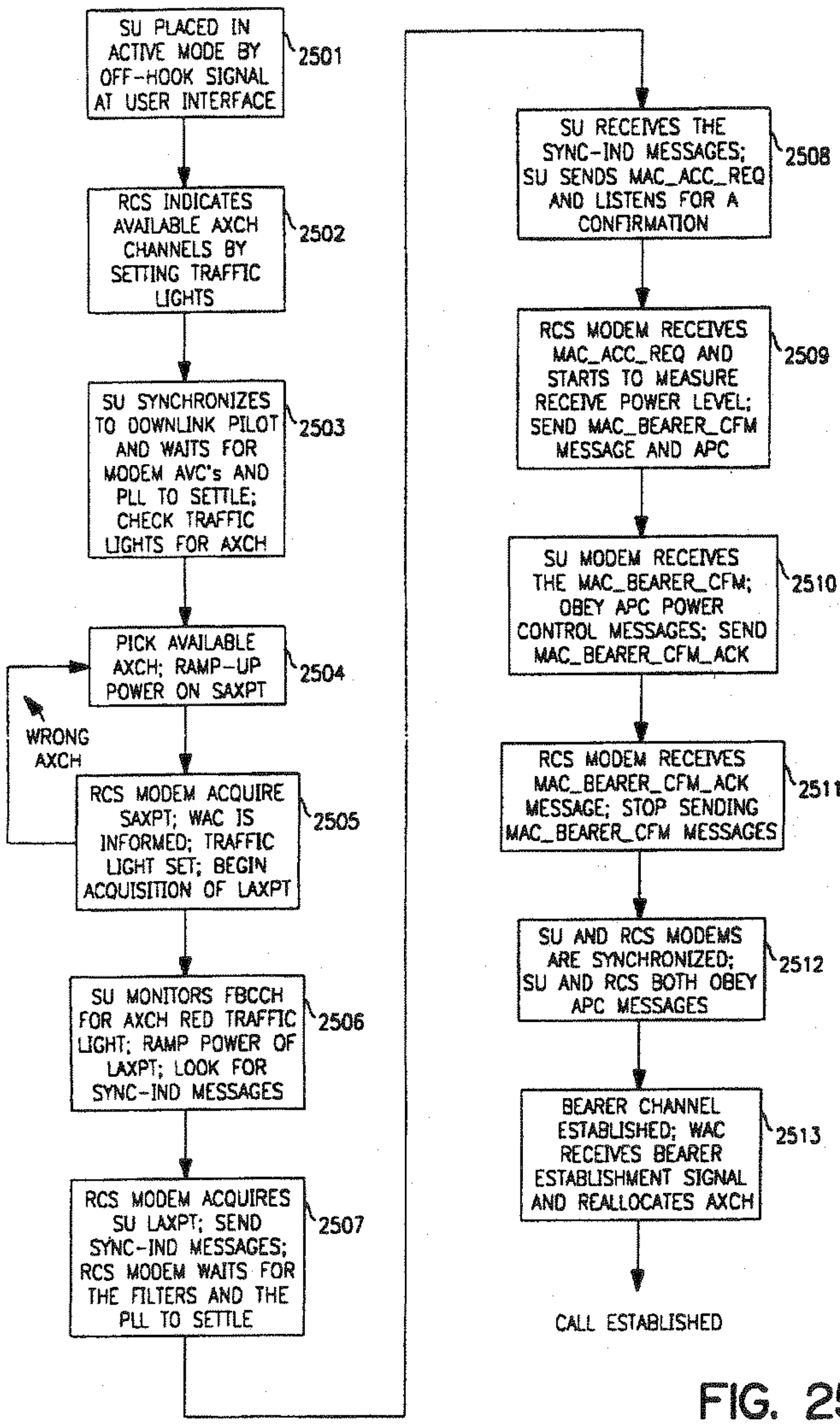

SU PLACED IN ACTIVE MODE BY OFF-HOOK SIGNAL AT USER INTERFACE
2501
RCS INDICATES AVAILABLE AXCH CHANNELS BY SETTING TRAFFIC LIGHTS
2502
SU SYNCHRONIZES TO DOWNLINK PILOT AND WAITS FOR MODEM AVC's AND PLL TO SETTLE; CHECK TRAFFIC LIGHTS FOR AXCH
2503
PICK AVAILABLE AXCH; RAMP-UP POWER ON SAXPT
2504
WRONG AXCH
RCS MODEM ACQUIRE SAXPT; WAC IS INFORMED; TRAFFIC LIGHT SET; BEGIN ACQUISITION OF LAXPT
2505
SU MONITORS FBCCH FOR AXCH RED TRAFFIC LIGHT; RAMP POWER OF LAXPT; LOOK FOR SYNC-IND MESSAGES
2506
RCS MODEM ACQUIRES SU LAXPT; SEND SYNC-IND MESSAGES; RCS MODEM WAITS FOR THE FILTERS AND THE PLL TO SETTLE
2507
SU RECEIVES THE SYNC-IND MESSAGES; SU SENDS MAC_ACC_REQ AND LISTENS FOR A CONFIRMATION
2508
RCS MODEM RECEIVES MAC_ACC_REQ AND STARTS TO MEASURE RECEIVE POWER LEVEL; SEND MAC_BEARER_CFM MESSAGE AND APC
2509
SU MODEM RECEIVES THE MAC_BEARER_CFM; OBEY APC POWER CONTROL MESSAGES; SEND MAC_BEARER_CFM_ACK
2510
RCS MODEM RECEIVES MAC_BEARER_CFM_ACK MESSAGE; STOP SENDING MAC_BEARER_CFM MESSAGES
2511
SU AND RCS MODEMS ARE SYNCHRONIZED; SU AND RCS BOTH OBEY APC MESSAGES
2512
BEARER CHANNEL ESTABLISHED; WAC RECEIVES BEARER ESTABLISHMENT SIGNAL AND REALLOCATES AXCH
2513
CALL ESTABLISHED

FIG. 25

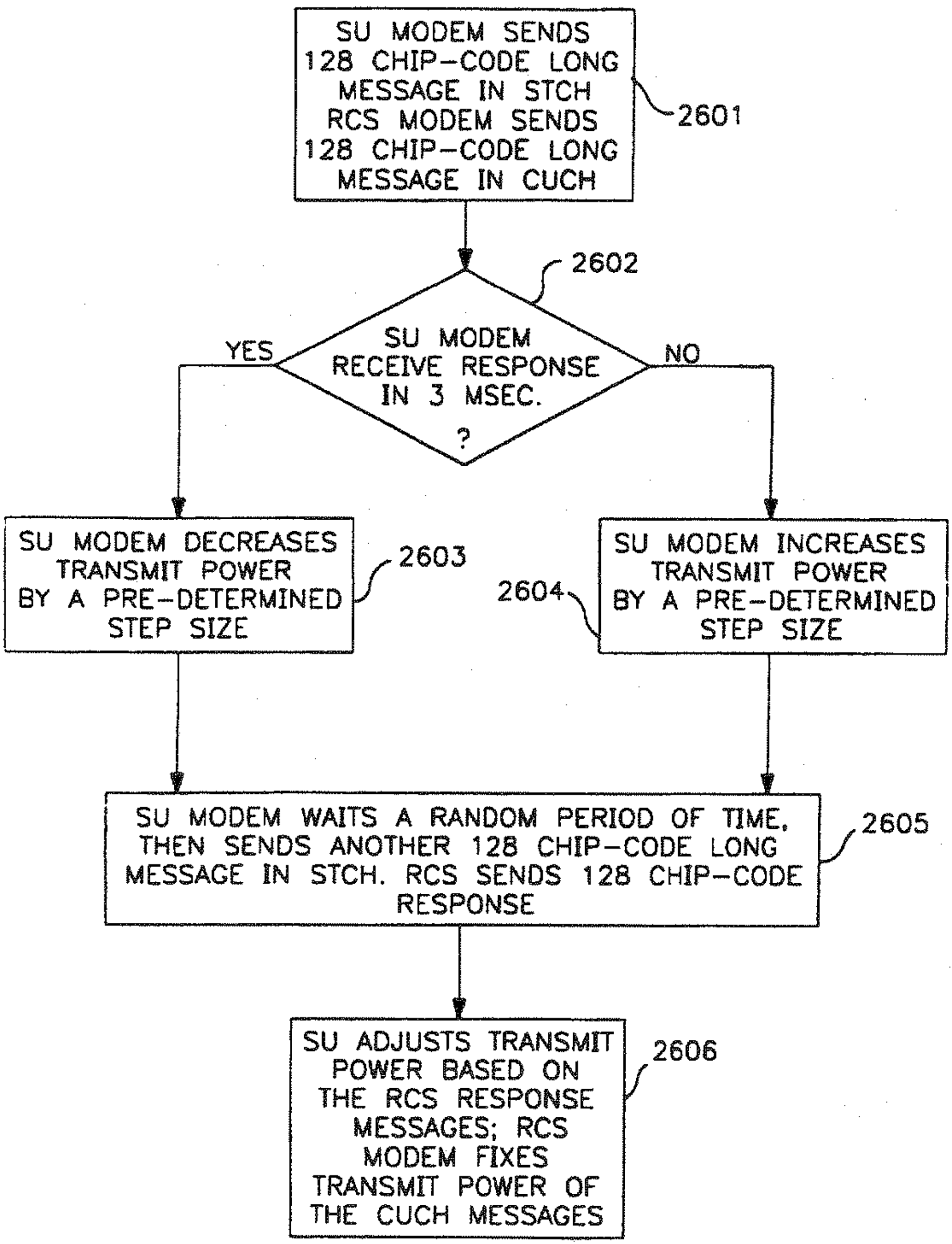
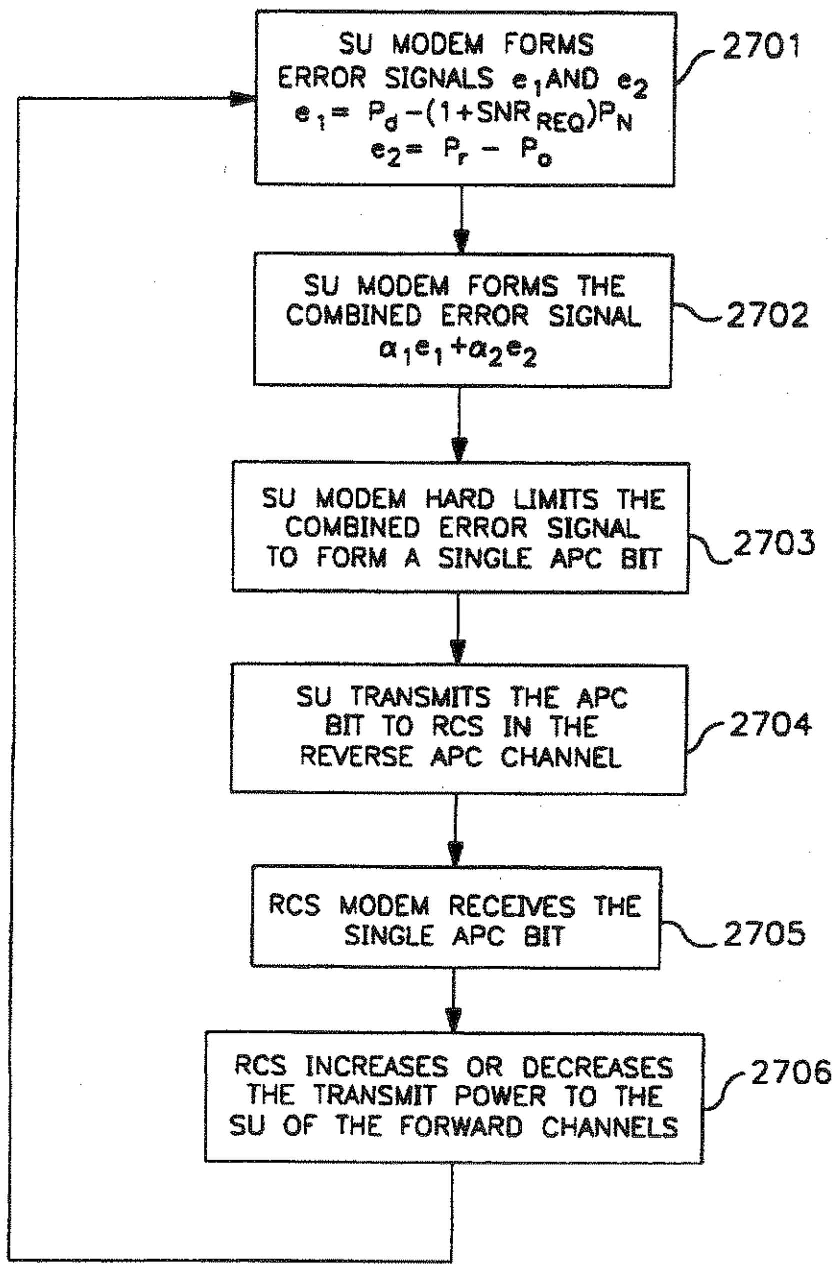

SU MODEM SENDS 128 CHIP-CODE LONG MESSAGE IN STCH RCS MODEM SENDS 128 CHIP-CODE LONG MESSAGE IN CUCH
2601
2602
SU MODEM RECEIVE RESPONSE IN 3 MSEC. ?
YES
NO
SU MODEM DECREASES TRANSMIT POWER BY A PRE-DETERMINED STEP SIZE
2603
2604
SU MODEM INCREASES TRANSMIT POWER BY A PRE-DETERMINED STEP SIZE
SU MODEM WAITS A RANDOM PERIOD OF TIME, THEN SENDS ANOTHER 128 CHIP-CODE LONG MESSAGE IN STCH. RCS SENDS 128 CHIP-CODE RESPONSE
2605
SU ADJUSTS TRANSMIT POWER BASED ON THE RCS RESPONSE MESSAGES; RCS MODEM FIXES TRANSMIT POWER OF THE CUCH MESSAGES
2606

FIG. 26



SU MODEM FORMS ERROR SIGNALS e_1 AND e_2
$e_1 = P_d - (1+SNR_{REQ})P_N$
$e_2 = P_r - P_o$
2701
SU MODEM FORMS THE COMBINED ERROR SIGNAL
$\alpha_1 e_1 + \alpha_2 e_2$
2702
SU MODEM HARD LIMITS THE COMBINED ERROR SIGNAL TO FORM A SINGLE APC BIT
2703
SU TRANSMITS THE APC BIT TO RCS IN THE REVERSE APC CHANNEL
2704
RCS MODEM RECEIVES THE SINGLE APC BIT
2705
RCS INCREASES OR DECREASES THE TRANSMIT POWER TO THE SU OF THE FORWARD CHANNELS
2706

FIG. 27

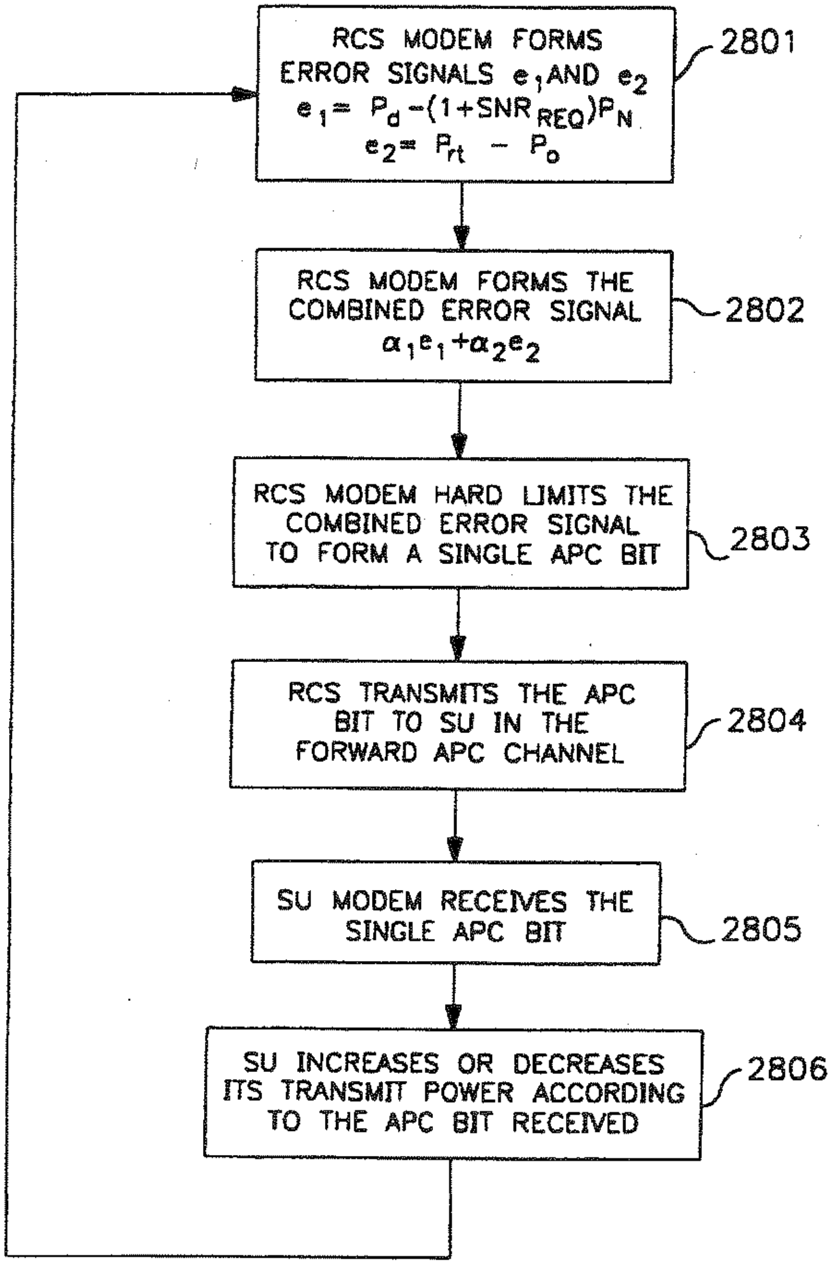

RCS MODEM FORMS ERROR SIGNALS e_1 AND e_2
$e_1 = P_d - (1+SNR_{REQ})P_N$
$e_2 = P_{rt} - P_o$
2801
RCS MODEM FORMS THE COMBINED ERROR SIGNAL $\alpha_1 e_1 + \alpha_2 e_2$
2802
RCS MODEM HARD LIMITS THE COMBINED ERROR SIGNAL TO FORM A SINGLE APC BIT
2803
RCS TRANSMITS THE APC BIT TO SU IN THE FORWARD APC CHANNEL
2804
SU MODEM RECEIVES THE SINGLE APC BIT
2805
SU INCREASES OR DECREASES ITS TRANSMIT POWER ACCORDING TO THE APC BIT RECEIVED
2806

FIG. 28

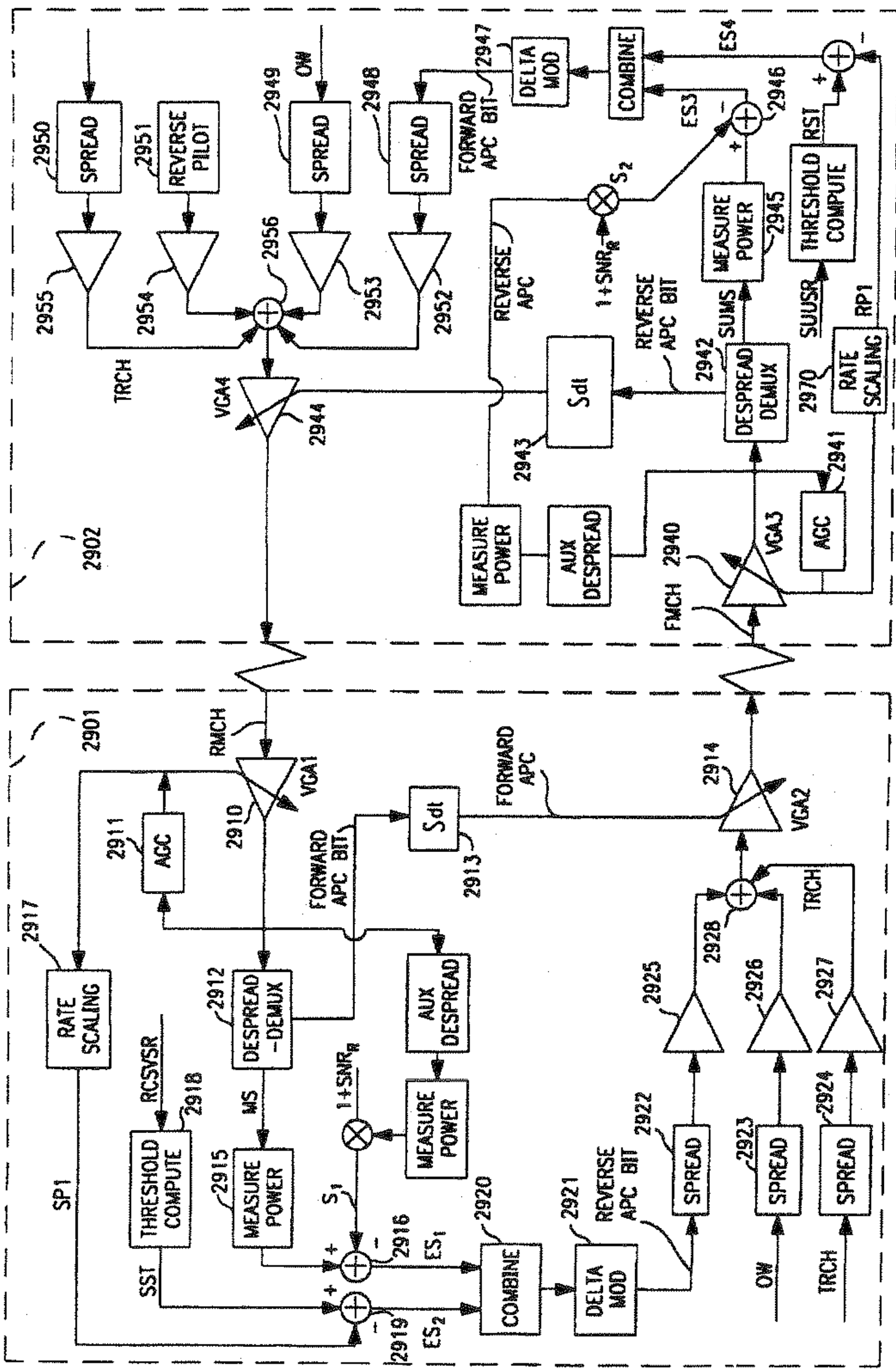
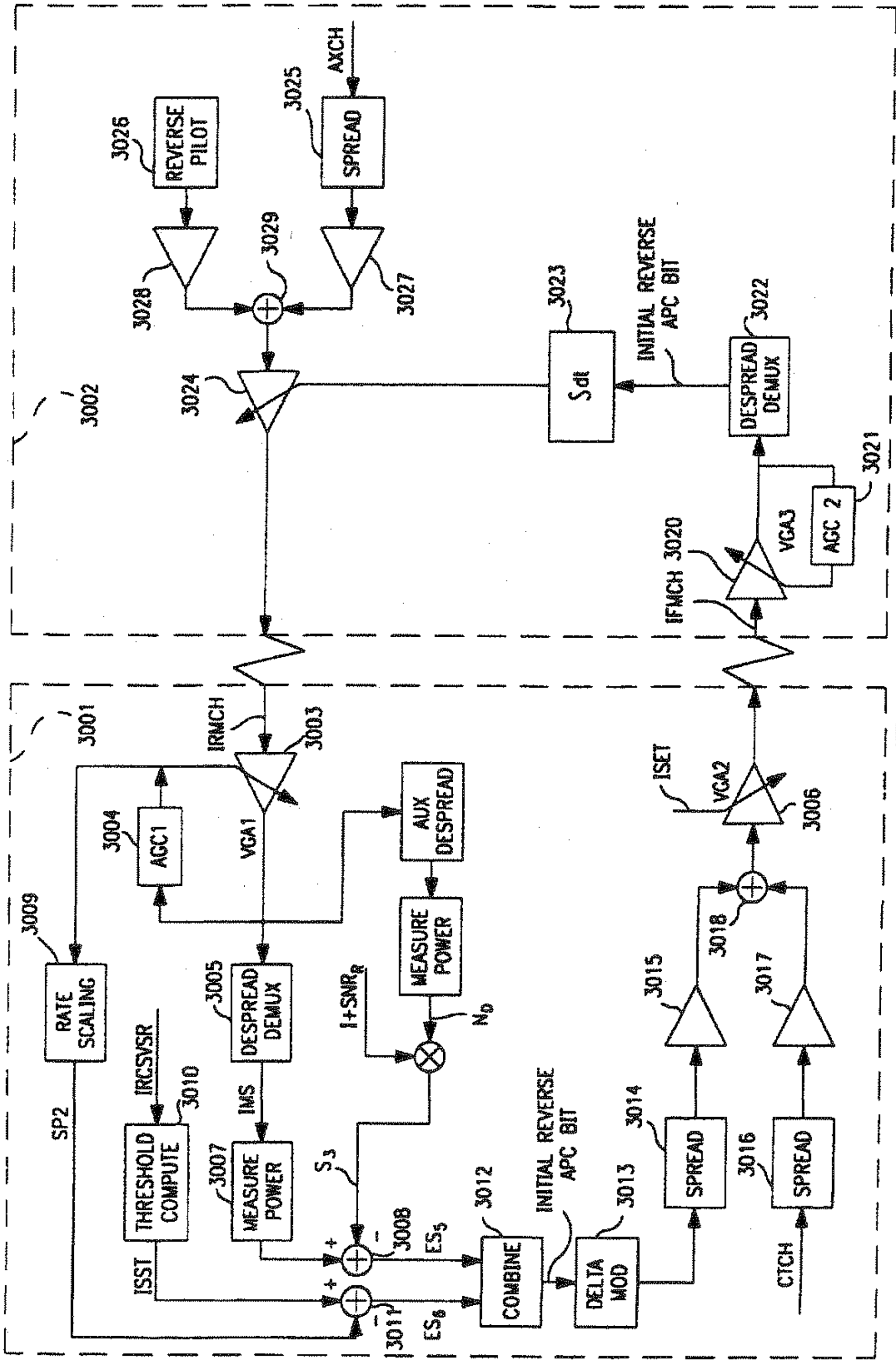

2902
SPREAD
2950
REVERSE PILOT
2951
OW
SPREAD
2949
SPREAD
2948
FORWARD APC BIT
2947
DELTA MOD
COMBINE
ES4
ES3
2946
RST
THRESHOLD COMPUTE
MEASURE POWER
2945
S2
1+SNR_R
REVERSE APC
2955
2954
2956
2953
2952
TRCH
VGA4
2944
Sdt
2943
REVERSE APC BIT
2942
SUMS
DESPREAD DEMUX
SUUSR
RP1
2970
RATE SCALING
2941
AGC
VGA3
FMCH
2940
MEASURE POWER
AUX DESPREAD
2901
RMCH
VGA1
2910
AGC
2911
FORWARD APC BIT
Sdt
2913
FORWARD APC
2914
VGA2
2917
RATE SCALING
SP1
RCSVSR
2918
THRESHOLD COMPUTE
SST
2912
DESPREAD -DEMUX
MS
2915
MEASURE POWER
AUX DESPREAD
MEASURE POWER
1+SNR_R
S1
2916
ES1
2919
ES2
2920
COMBINE
2921
DELTA MOD
REVERSE APC BIT
2922
SPREAD
2923
SPREAD
OW
2924
SPREAD
TRCH
2925
2926
2927
2928
TRCH

FIG. 29



3002
3026
REVERSE PILOT
3025
SPREAD
AXCH
3028
3029
3027
3024
3023
S_{dt}
INITIAL REVERSE APC BIT
3022
DESPREAD DEMUX
3021
AGC 2
VGA3
IFMCH 3020
3001
IRMCH
3003
3004
AGC1
VGA1
AUX DESPREAD
MEASURE POWER
N_D
$1+SNR_R$
3009
RATE SCALING
3005
DESPREAD DEMUX
IRCSVSR
3010
THRESHOLD COMPUTE
IMS
3007
MEASURE POWER
SP2
S_3
ISST
3008
ES_5
3011
ES_6
3012
COMBINE
INITIAL REVERSE APC BIT
3013
DELTA MOD
3014
SPREAD
3015
3016
SPREAD
CTCH
3017
3018
ISET
VGA2
3006

FIG. 30

CODE DIVISION MULTIPLE ACCESS (CDMA) COMMUNICATION SYSTEM

This application claims the benefit of U.S. Provisional Application 60/000,775 filed Jun. 30, 1995.

BACKGROUND OF THE INVENTION

The present invention generally pertains to Code Division Multiple Access (CDMA) communications, also known as spread-spectrum communications. More particularly, the present invention pertains to a system and method for providing a high capacity, CDMA communications system which provides for one or more simultaneous user bearer channels over a given radio frequency, allowing dynamic allocation of bearer channel rate while rejecting multipath interference.

DESCRIPTION OF THE RELEVANT ART

Providing quality telecommunication services to user groups which are classified as remote, such as rural telephone systems and telephone systems in underdeveloped countries, has proved to be a challenge in recent years. These needs have been partially satisfied by wireless radio services, such as fixed or mobile frequency division multiplex (FDM), frequency division multiple access (FDMA), time division multiplex (TDM), time division multiple access (TDMA) systems, combination frequency and time division systems (FD/TDMA), and other land mobile radio systems. Usually, these remote services are faced with more potential users than can be supported simultaneously by their frequency or spectral bandwidth capacity.

Recognizing these limitations, recent advances in wireless communications have used spread spectrum modulation techniques to provide simultaneous communication by multiple users. Spread spectrum modulation refers to modulating a information signal with a spreading code signal; the spreading code signal being generated by a code generator where the period Tc of the spreading code is substantially less than the period of the information data bit or symbol signal. The code may modulate the carrier frequency upon which the information has been sent, called frequency-hopped spreading, or may directly modulate the signal by multiplying the spreading code with the information data signal, called direct-sequence spreading (DS). Spread-spectrum modulation produces a signal with bandwidth substantially greater than that required to transmit the information signal. Synchronous reception and despreading of the signal at the receiver recovers the original information. A synchronous demodulator in the receiver uses a reference signal to synchronize the despreading circuits to the input spread-spectrum modulated signal to recover the carrier and information signals. The reference signal can be a spreading code which is not modulated by an information signal. Such use of a synchronous spread-spectrum modulation and demodulation for wireless communication is described in U.S. Pat. No. 5,228,056 entitled SYNCHRONOUS SPREAD-SPECTRUM COMMUNICATIONS SYSTEM AND METHOD by Donald L. Schilling, which techniques are incorporated herein by reference.

Spread-spectrum modulation in wireless networks offers many advantages because multiple users may use the same frequency band with minimal interference to each user's receiver. Spread-spectrum modulation also reduces effects from other sources of interference. In addition, synchronous spread-spectrum modulation and demodulation techniques may be expanded by providing multiple message channels

for a single user, each spread with a different spreading code, while still transmitting only a single reference signal to the user. Such use of multiple message channels modulated by a family of spreading codes synchronized to a pilot spreading code for wireless communication is described in U.S. Pat. No. 5,166,951 entitled HIGH CAPACITY SPREAD-SPECTRUM CHANNEL by Donald L. Schilling, which is incorporated herein by reference.

One area in which spread-spectrum techniques are used is in the field of mobile cellular communications to provide personal communication services (PCS). Such systems desirably support large numbers of users, control Doppler shift and fade, and provide high speed digital data signals with low bit error rates. These systems employ a family of orthogonal or quasi-orthogonal spreading codes, with a pilot spreading code sequence synchronized to the family of codes. Each user is assigned one of the spreading codes as a spreading function. Related problems of such a system are: supporting a large number of users with the orthogonal codes, handling reduced power available to remote units, and handling multipath fading effects. Solutions to such problems include using phased-array antennas to generate multiple steerable beams, using very long orthogonal or quasi-orthogonal code sequences. These sequences may be reused by cyclic shifting of the code synchronized to a central reference, and diversity combining of multipath signals. Such problems associated with spread spectrum communications, and methods to increase capacity of a multiple access, spread-spectrum system are described in U.S. Pat. No. 4,901,307 entitled SPREAD SPECTRUM MULTIPLE ACCESS COMMUNICATION SYSTEM USING SATELLITE OR TERRESTRIAL REPEATERS by Gilhousen et al. which is incorporated herein by reference.

The problems associated with the prior art systems focus around reliable reception and synchronization of the receiver despreading circuits to the received signal. The presence of multipath fading introduces a particular problem with spread spectrum receivers in that a receiver must somehow track the multipath components to maintain code-phase lock of the receiver's despreading means with the input signal. Prior art receivers generally track only one or two of the multipath signals, but this method is not satisfactory because the combined group of low power multipath signal components may actually contain far more power than the one or two strongest multipath components. The prior art receivers track and combine the strongest components to maintain a predetermined Bit Error Rate (BER) of the receiver. Such a receiver is described, for example, in U.S. Pat. No. 5,109,390 entitled DIVERSITY RECEIVER IN A CDMA CELLULAR TELEPHONE SYSTEM by Gilhousen et al. A receiver that combines all multipath components, however, is able to maintain the desired BER with a signal power that is lower than that of prior art systems because more signal power is available to the receiver. Consequently, there is a need for a spread spectrum communication system employing a receiver that tracks substantially all of the multipath signal components, so that substantially all multipath signals may be combined in the receiver, and hence the required transmit power of the signal for a given BER may be reduced.

Another problem associated with multiple access, spread-spectrum communication systems is the need to reduce the total transmitted power of users in the system, since users may have limited available power. An associated problem requiring power control in spread-spectrum systems is related to the inherent characteristic of spread-spectrum systems that one user's spread-spectrum signal is received

by another user's receiver as noise with a certain power level. Consequently, users transmitting with high levels of signal power may interfere with other users' reception. Also, if a user moves relative to another user's geographic location, signal fading and distortion require that the users adjust their transmit power level to maintain a particular signal quality. At the same time, the system should keep the power that the base station receives from all users relatively constant. Finally, because it is possible for the spread-spectrum system to have more remote users than can be supported simultaneously, the power control system should also employ a capacity management method which rejects additional users when the maximum system power level is reached.

Prior spread-spectrum systems have employed a base station that measures a received signal and sends an adaptive power control (APC) signal to the remote users. Remote users include a transmitter with an automatic gain control (AGC) circuit which responds to the APC signal. In such systems the base station monitors the overall system power or the power received from each user, and sets the APC signal accordingly. Such a spread-spectrum power control system and method is described in U.S. Pat. No. 5,299,226 entitled ADAPTIVE POWER CONTROL FOR A SPREAD SPECTRUM COMMUNICATION SYSTEM AND METHOD, and U.S. Pat. No. 5,093,840 entitled ADAPTIVE POWER CONTROL FOR A SPREAD SPECTRUM TRANSMITTER, both by Donald L. Schilling and incorporated herein by reference. This open loop system performance may be improved by including a measurement of the signal power received by the remote user from the base station, and transmitting an APC signal back to the base station to effectuate a closed loop power control method. Such closed loop power control is described, for example, in U.S. Pat. No. 5,107,225 entitled HIGH DYNAMIC RANGE CLOSED LOOP AUTOMATIC GAIN CONTROL CIRCUIT to Charles E. Wheatley, III et al. and incorporated herein by reference.

These power control systems, however, exhibit several disadvantages. First, the base station must perform complex power control algorithms, increasing the amount of processing in the base station. Second, the system actually experiences several types of power variation: variation in the noise power caused by the variation in the number of users and variations in the received signal power of a particular bearer channel. These variations occur with different frequency, so simple power control algorithms can be optimized to compensate for only one of the two types of variation. Finally, these power algorithms tend to drive the overall system power to a relatively high level. Consequently, there is a need for a spread-spectrum power control method that rapidly responds to changes in bearer channel power levels, while simultaneously making adjustments to all users' transmit power in response to changes in the number of users. Also, there is a need for an improved spread-spectrum communication system employing a closed loop power control system which minimizes the system's overall power requirements while maintaining a sufficient BER at the individual remote receivers. In addition, such a system should control the initial transmit power level of a remote user and manage total system capacity.

Spread-spectrum communication systems desirably should support large numbers of users, each of which has at least one communication channel. In addition, such a system should provide multiple generic information channels to broadcast information to all users and to enable users to gain access to the system. Using prior art spread-spectrum systems this could only be accomplished by generating large numbers of spreading code sequences.

Further, spread-spectrum systems should use sequences that are orthogonal or nearly orthogonal to reduce the probability that a receiver locks to the wrong spreading code sequence or phase. The use of such orthogonal codes and the benefits arising therefrom are outlined in U.S. Pat. No. 5,103,459 entitled SYSTEM AND METHOD FOR GENERATING SIGNAL WAVEFORMS IN A CDMA CELLULAR TELEPHONE SYSTEM, by Gilhousen et al. and U.S. Pat. No. 5,193,094 entitled METHOD AND APPARATUS FOR GENERATING SUPER-ORTHOGONAL CONVOLUTIONAL CODES AND THE DECODING THEREOF, by Andrew J. Viterbi, both of which are incorporated herein by reference. However, generating such large families of code sequences with such properties is difficult. Also, generating large code families requires generating sequences which have a long period before repetition. Consequently, the time a receiver takes to achieve synchronization with such a long sequence is increased. Prior art spreading code generators often combine shorter sequences to make longer sequences, but such sequences may no longer be sufficiently orthogonal. Therefore, there is a need for an improved method for reliably generating large families of code sequences that exhibit nearly orthogonal characteristics and have a long period before repetition, but also include the benefit of a short code sequence that reduces the time to acquire and lock the receiver to the correct code phase. In addition, the code generation method should allow generation of codes with any period, since the spreading code period is often determined by parameters used such as data rate or frame size.

Another desirable characteristic of spreading code sequences is that the transition of the user data value occur at a transition of the code sequence values. Since data typically has a period which is divisible by 2^N, such a characteristic usually requires the code-sequence to be an even length of 2^N. However, code generators, as is well known in the art, generally use linear feedback shift registers which generate codes of length 2^N-1. Some generators include a method to augment the generated code sequence by inserting an additional code value, as described, for example, in U.S. Pat. No. 5,228,054 entitled POWER-OF-TWO LENGTH PSEUDONOISE SEQUENCE GENERATOR WITH FAST OFFSET ADJUSTMENT by Timothy Rueth et al and incorporated herein by reference. Consequently, the spread-spectrum communication system should also generate spreading code sequences of even length.

Finally, the spread-spectrum communication system should be able to handle many different types of data, such as FAX, voiceband data, and ISDN, in addition to traditional voice traffic. To increase the number of users supported, many systems employ encoding techniques such as ADPCM to achieve "compression" of the digital telephone signal. FAX, ISDN and other data, however, require the channel to be a clear channel. Consequently, there is a need for a spread spectrum communication system that supports compression techniques that also dynamically modify the spread spectrum bearer channel between an encoded channel and a clear channel in response to the type of information contained in the user's signal.

SUMMARY OF THE INVENTION

The present invention is embodied in a multiple access, spread-spectrum communication system which processes a

plurality of information signals received simultaneously over telecommunication lines for simultaneous transmission over a radio frequency (RF) channel as a code-division-multiplexed (CDM) signal. The system includes a radio carrier station (RCS) which receives a call request signal that corresponds to a telecommunication line information signal, and a user identification signal that identifies a user to which the call request and information signal are addressed. The receiving apparatus is coupled to a plurality of code division multiple access (CDMA) modems, one of which provides a global pilot code signal and a plurality of message code signals, and each of the CDMA modems combines one of the plurality of information signals with its respective message code signal to provide a spread-spectrum processed signal. The plurality of message code signals of the plurality of CDMA modems are synchronized to the global pilot code signal. The system also includes assignment apparatus that is responsive to a channel assignment signal for coupling the respective information signals received on the telecommunication lines to indicated ones of the plurality of modems; The assignment apparatus is coupled to a time-slot exchange means. The system further includes a system channel controller coupled to a remote call-processor and to the time-slot exchange means. The system channel controller is responsive to the user identification signal, to provide the channel assignment signal. In the system, an RF transmitter is connected to all of the modems to combine the plurality of spread-spectrum processed message signals with the global pilot code signal to generate a CDM signal. The RF transmitter also modulates a carrier signal with the CDM signal and transmits the modulated carrier signal through an RF communication channel.

The transmitted CDM signal is received from the RF communication channel by a subscriber unit (SU) which processes and reconstructs the transmitted information signal assigned to the subscriber. The SU includes a receiving means for receiving and demodulating the CDM signal from the carrier. In addition, the SU comprises a subscriber unit controller and a CDMA modem which includes a processing means for acquiring the global pilot code and despreading the spread-spectrum processed signal to reconstruct the transmitted information signal.

The RCS and the SUs each contain CDMA modems for transmission and reception of telecommunication signals including information signals and connection control signals. The CDMA modem comprises a modem transmitter having: a code generator for providing an associated pilot code signal and for generating a plurality of message code signals; a spreading means for combining each of the information signals, with a respective one of the message code signals to generate spread-spectrum processed message signals; and a global pilot code generator which provides a global pilot code signal to which the message code signals are synchronized.

The CDMA modem also comprises a modem receiver having associated pilot code acquisition and tracking logic. The associated pilot code acquisition logic includes an associated pilot code generator; a group of associated pilot code correlators for correlating code-phase delayed versions of the associated pilot signal with a receive CDM signal for producing a despread associated pilot signal. The code phase of the associated pilot signal is changed responsive to an acquisition signal value until a detector indicates the presence of the despread associated pilot code signal by changing the acquisition signal value. The associated pilot code signal is synchronized to the global pilot signal. The associated pilot code tracking logic adjusts the associated pilot code signal in phase responsive to the acquisition signal so that the signal power level of the despread associated pilot code signal is maximized. Finally, the CDMA modem receiver includes a group of message signal acquisition circuits. Each message signal acquisition circuit includes a plurality of receive message signal correlators for correlating one of the local receive message code signals with the CDM signal to produce a respective despread receive message signal.

To generate large families of nearly mutually orthogonal codes used by the CDMA modems, the present invention includes a code sequence generator. The code sequences are assigned to a respective logical channel of the spread-spectrum communication system, which includes In-phase (I) and Quadrature (Q) transmission over RF communication channels. One set of sequences is used as pilot sequences which are code sequences transmitted without modulation by a data signal. The code sequence generator circuit includes a long code sequence generator including a linear feedback shift register, a memory which provides a short, even code sequence, and a plurality of cyclic shift, feedforward sections which provide other members of the code family which exhibit minimal correlation with the code sequence applied to the feedforward circuit. The code sequence generator further includes a group of code sequence combiners for combining each phase shifted version of the long code sequence with the short, even code sequence to produce a group, or family, of nearly mutually orthogonal codes.

Further, the present invention includes several methods for efficient utilization of the spread-spectrum channels. First, the system includes a bearer channel modification system which comprises a group of message channels between a first transceiver and second transceiver. Each of the group of message channels supports a different information signal transmission rate. The first transceiver monitors a received information signal to determine the type of information signal that is received, and produces a coding signal relating to the coding signal. If a certain type of information signal is present, the first transitive switches transmission from a first message channel to a second message channel to support the different transmission rate. The coding signal is transmitted by the first transitive to the second transitive, and the second transitive switches to the second message channel to receive the information signal at a different transmission rate.

Another method to increase efficient utilization of the bearer message channels is the method of idle-code suppression used by the present invention. The spread-spectrum transitive receives a digital data information signal including a predetermined flag pattern corresponding to an idle period. The method includes the steps of: 1) delaying and monitoring the digital data signal; 2) detecting the predetermined flag pattern; 3) suspending transmission of the digital data signal when the flag pattern is detected; and 4) transmitting the data signal as a spread-spectrum signal when the flag pattern is not detected.

The present invention includes a system and method for closed loop automatic power control (AC) for the RCS and SUs of the spread-spectrum communication system. The SUs transmit spread-spectrum signals, the RCS acquires the spread-spectrum signals, and the RCS detects the received power level of the spread-spectrum signals plus any interfering signal including noise. The AC system includes the RCS and a plurality of SUs, wherein the RCS transmits a plurality of forward channel information signals to the SUs

as a plurality of forward channel spread-spectrum signals having a respective forward transmit power level, and each SU transmits to the base station at least one reverse spread-spectrum signal having a respective reverse transmit power level and at least one reverse channel spread-spectrum signal which includes a reverse channel information signal.

The AC includes an automatic forward power control (AFPC) system, and an automatic reverse power control (ARPC) system. The AFPC system operates by measuring, at the SU, a forward signal-to-noise ratio of the respective forward channel information signal, generating a respective forward channel error signal corresponding to a forward error between the respective forward signal-to-noise ratio and a pre-determined signal-to-noise value, and transmitting the respective forward channel error signal as part of a respective reverse channel information signal from the SU to the RCS. The RCS includes a plural number of AFPC receivers for receiving the reverse channel information signals and extracting the forward channel error signals from the respective reverse channel information signals. The RCU also adjusts the respective forward transmit power level of each one of the respective forward spread-spectrum signals responsive to the respective forward error signal.

The ARPC system operates by measuring, in the RCS, a reverse signal-to-noise ratio of each of the respective reverse channel information signals, generating a respective reverse channel error signal representing an error between the respective reverse channel signal-to-noise ratio and a respective pre-determined signal-to-noise value, and transmitting the respective reverse channel error signal as a part of a respective forward channel information signal to the SU. Each SU includes an ARPC receiver for receiving the forward channel information signal and extracting the respective reverse error signal from the forward channel information signal. The SU adjusts the reverse transmit power level of the respective reverse spread-spectrum signal responsive to the respective reverse error signal.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a code division multiple access communication system according to the present invention.

FIG. 2*a* is a block diagram of a 36 stage linear shift register suitable for use with long spreading code of the code generator of the present invention.

FIG. 2*b* is a block diagram of circuitry which illustrates the feed) forward operation of the code generator.

FIG. 2*c* is a block diagram of an exemplary code generator of the present invention including circuitry for generating spreading code sequences from the long spreading codes and the short spreading codes.

FIG. 2*d* is an alternate embodiment of the code generator circuit to including delay elements to compensate for electrical circuit delays.

FIG. 3*a* is a graph of the constellation points of the pilot spreading code QPSK signal.

FIG. 3*b* is a graph of the constellation points of the message channel QPSK signal.

FIG. 3*c* is a block diagram of exemplary circuitry which implements the method of tracking the received spreading code phase of the present invention.

FIG. 4 is a block diagram of the tracking circuit that tracks the median of the received multipath signal components.

FIG. 5*a* is a block diagram of the tracking circuit that tracks the centroid of the received multipath signal components.

FIG. 5*b* is a block diagram of the Adaptive Vector Correlator.

FIG. 6 is a block diagram of exemplary circuitry which implements the acquisition decision method of the correct spreading code phase of the received pilot code of the present invention.

FIG. 7 is a block diagram of an exemplary pilot rake filter which includes the tracking circuit and digital phase locked loop for despreading the pilot spreading code, and generator of the weighting factors of the present invention.

FIG. 8*a* is a block diagram of an exemplary adaptive vector correlator and matched filter for despreading and combining the multipath components of the present invention.

FIG. 8*b* is a block diagram of an alternative implementation of the adaptive vector correlator and adaptive matched filter for despreading and combining the multipath components of the present invention.

FIG. 8*c* is a block diagram of an alternative embodiment of the adaptive vector correlator and adaptive matched filter for despreading and combining the multipath components of the present invention.

FIG. 8*d* is a block diagram of the Adaptive Matched Filter of one embodiment of the present invention.

FIG. 9 is a block diagram of the elements of an exemplary radio carrier station (RCS) of the present invention.

FIG. 10 is a block diagram of the elements of an exemplary multiplexer suitable for use in the RCS shown in FIG. 9.

FIG. 11 is a block diagram of the elements of an exemplary wireless access controller (WAC) of the RCS shown in FIG. 9.

FIG. 12 is a block diagram of the elements of an exemplary modem interface unit (MIU) of the RCS shown in FIG. 9.

FIG. 13 is a high level block diagram showing the transmit, receive, control, and code generation circuitry of the CDMA modem.

FIG. 14 is a block diagram of the transmit section of the CDMA modem.

FIG. 15 is a block diagram of an exemplary modem input signal receiver.

FIG. 16 is a block diagram of an exemplary convolutional encoder as used in the present invention.

FIG. 17 is a block diagram of the receive section of the CDMA modem.

FIG. 18 is a block diagram of an exemplary adaptive matched filter as used in the CDMA modem receive section.

FIG. 19 is a block diagram of an exemplary pilot rake as used in the CDMA modem receive section.

FIG. 20 is a block diagram of an exemplary auxiliary pilot rake as used in the CDMA modem receive section.

FIG. 21 is a block diagram of an exemplary video distribution circuit (VDC) of the RCS shown in FIG. 9.

FIG. 22 is a block diagram of an exemplary RF transmitter/receiver and exemplary power amplifiers of the RCS shown in FIG. 9.

FIG. 23 is a block diagram of an exemplary subscriber unit (SU) of the present invention.

FIG. 24 is a flow-chart diagram of an exemplary call establishment algorithm for an incoming call request used by the present invention for establishing a bearer channel between an RCS and an SU.

FIG. 25 is a flow-chart diagram of an exemplary call establishment algorithm for an outgoing call request used by the present invention for establishing a bearer channel between an RCS and an SU.

FIG. 26 is a flow-chart diagram of an exemplary maintenance power control algorithm of the present invention.

FIG. 27 is a flow-chart diagram of an exemplary automatic forward power control algorithm of the present invention.

FIG. 28 is a flow-chart diagram of an exemplary automatic reverse power control algorithm of the present invention.

FIG. 29 is a block diagram of an exemplary closed loop power control system of the present invention when the bearer channel is established.

FIG. 30 is a block diagram of an exemplary closed loop power control system of the present invention during the process of establishing the bearer channel.

GLOSSARY OF ACRONYMS

Acronym	Definition
AC	Assigned Channels
A/D	Analog-to-Digital
ADPCM	Adaptive Differential Pulse Code Modulation
AFPC	Automatic Forward Power Control
AGC	Automatic Gain Control
AMF	Adaptive Matched Filter
APC	Automatic Power Control
ARPC	Automatic Reverse Power Control
ASPT	Assigned Pilot
AVC	Adaptive Vector Correlator
AXCH	Access Channel
B-CDMA	Broadband Code Division Multiple Access
BCM	Bearer Channel Modification
BER	Bit Error Rate
BS	Base Station
CC	Call Control
CDM	Code Division Multiplex
CDMA	Code Division Multiple Access
CLK	Clock Signal Generator
CO	Central Office
CTCH	Control Channel
CUCH	Check-Up Channel
dB	Decibels
DCC	Data Combiner Circuitry
DI	Distribution Interface
DLL	Delay Locked Loop
DM	Delta Modulator
DS	Direct Sequence
EPIC	Extended PCM Interface Controller
FBCH	Fast Broadcast Channel
FDM	Frequency Division Multiplex
FD/TDMA	Frequency & Time Division Systems
FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
FSK	Frequency Shift Keying
FSU	Fixed Subscriber Unit
GC	Global Channel
GLPT	Global Pilot
GPC	Global Pilot Code
GPSK	Gaussian Phase Shift Keying
GPS	Global Positioning System
HPPC	High Power Passive Components
HSB	High Speed Bus
I	In-Phase
IC	Interface Controller
ISDN	Integrated Services Digital Network
ISST	Initial System Signal Threshold
LAXPT	Long Access Pilot
LAPD	Link Access Protocol
LCT	Local Craft Terminal
LE	Local Exchange
LFSR	Linear Feedback Shift Register

-continued

GLOSSARY OF ACRONYMS

Acronym	Definition
LI	Line Interface
LMS	Least Mean Square
LOL	Loss of Code Lock
LPF	Low Pass Filter
LSR	Linear Shift Register
MISR	Modem Input Signal Receiver
MIU	Modem Interface Unit
MM	Mobility Management
MOI	Modem Output Interface
MPC	Maintenance Power Control
MPSK	M-ary Phase Shift Keying
MSK	Minimum Shift Keying
MSU	Mobile Subscriber Unit
NE	Network Element
OMS	Operation and Maintenance System
OS	Operations System
OQPSK	Offset Quadrature Phase Shift Keying
OW	Order Wire
PARK	Portable Access Rights Key
PBX	Private Branch Exchange
PCM	Pulse Coded Modulation
PCS	Personal Communication Services
PG	Pilot Generator
PLL	Phase Locked Loop
PLT	Pilot
PN	Pseudonoise
POTS	Plain Old Telephone Service
PSTN	Public Switched Telephone Network
Q	Quadrature
QPSK	Quadrature Phase Shift Keying
RAM	Random Access Memory
RCS	Radio Carrier Station
RDI	Receiver Data Input Circuit
RDU	Radio Distribution Unit
RF	Radio Frequency
RLL	Radio Local Loop
SAXPT	Short Access Channel Pilots
SBCH	Slow Broadcast Channel
SHF	Super High Frequency
SIR	Signal Power to Interface Noise Power Ratio
SLIC	Subscriber Line Interface Circuit
SNR	Signal-to-Noise Ratio
SPC	Service PC
SPRT	Sequential Probability Ratio Test
STCH	Status Channel
SU	Subscriber Unit
TDM	Time Division Multiplexing
TMN	Telecommunication Management Network
TRCH	Traffic Channels
TSI	Time-Slot Interchanger
TX	Transmit
TXIDAT	I-Modem Transmit Data Signal
TXQDAT	Q-Modem Transmit Data Signal
UHF	Ultra High Frequency
VCO	Voltage Controlled Oscillator
VDC	Video Distribution Circuit
VGA	Variable Gain Amplifier
VHF	Very High Frequency
WAC	Wireless Access Controller

DESCRIPTION OF THE EXEMPLARY EMBODIMENT

General System Description

The system of the present invention provides local-loop telephone to service using radio links between one or more base stations and multiple remote subscriber units. In the exemplary embodiment, a radio link is described for a base station communicating with a fixed subscriber unit (FSU), but the system is equally applicable to systems including multiple base stations with radio links to both FSUs and Mobile Subscriber Units (MSUs). Consequently, the remote subscriber units are referred to herein as Subscriber Units (SUs).

Referring to FIG. 1, Base Station (BS) 101 provides call connection to a local exchange (LE) 103 or any other telephone network switching interface, such as a private branch exchange (PBX) and includes a Radio Carrier Station (RCS) 104. One or more RCSs 104, 105, 110 connect to a Radio Distribution Unit (RDU) 102 through links 131, 132, 137, 138, 139, and RDU 102 interfaces with LE 103 by transmitting and receiving call set-up, control, and information signals through telco links 141, 142, 150. SUs 116, 119 communicate with the RCS 104 through radio links 161, 162, 163, 164, 165. Alternatively, another embodiment of the invention includes several SUs and a "master" SU with functionality similar to the RCS. Such an embodiment may or may not have connection to a local telephone network.

The radio links 161 to 165 operate within the frequency bands of the DCS1800 standard (1.71–1.785 Ghz and 1.805–1.880 GHz); the US-PCS standard (1.85–1.99 Ghz); and the CEPT standard (2.0–2.7 GHz). Although these to bands are used in described embodiment, the invention is equally applicable to the entire UHF to SHF bands, including bands from 2.7 GHz to 5 GHz. The transmit and receive bandwidths are multiples of 3.5 MHz starting at 7 MHz, and multiples of 5 MHz starting at 10 MHz, respectively. The described system includes bandwidths of 7, 10, 10.5, 14 and 15 MHz. In the exemplary embodiment of the invention, the minimum guard band between the Uplink and Downlink is 20 MHz, and is desirably at least three times the signal bandwidth. The duplex separation is between 50 to 175 MHz, with the described invention using 50, 75, 80, 95, and 175 MHz. Other frequencies may also be used.

Although the described embodiment uses different spread-spectrum bandwidths centered around a carrier for the transmit and receive spread-spectrum channels, the present method is readily extended to systems using multiple spread-spectrum bandwidths for the transmit channels and multiple spread-spectrum bandwidths for the receive channels. Alternatively, because spread-spectrum communication systems have the inherent feature that one user's transmission appears as noise to another user's despreading receiver, an embodiment may employ the same spread-spectrum channel for both the transmit and receive path channels. In other words, Uplink and Downlink transmissions can occupy the same frequency band. Furthermore, the present method may be readily extended to multiple CDMA frequency bands, each conveying a respectively different set of messages, uplink, downlink or uplink and downlink.

The spread binary symbol information is transmitted over the radio links 161 to 165 using Quadrature Phase Shift Keying (QPSK) modulation with Nyquist Pulse Shaping in the present embodiment, although other modulation techniques may be used, including, but not limited to, Offset QPSK (OQPSK) and Minimum Shift Keying (MSK), Gaussian Phase Shift Keying (GPSK) and M-ary Phase Shift Keying (MPSK)

The radio links 161 to 165 incorporate Broadband Code Division Multiple Access (B-CDMA™) as the mode of transmission in both the Uplink and Downlink directions. CDMA (also known as Spread Spectrum) communication techniques used in multiple access systems are well-known, and are described in U.S. Pat. No. 5,228,056 entitled SYNCHRONOUS SPREAD-SPECTRUM COMMUNICATION SYSTEM AND METHOD by Donald T Schilling. The system described utilizes the Direct Sequence (DS) spreading technique. The CDMA modulator performs the spread-spectrum spreading code sequence generation, which can be a pseudonoise (PN) sequence; and complex DS modulation of the QPSK signals with spreading code sequences for the In-phase (I) and Quadrature (Q) channels. Pilot signals are generated and transmitted with the modulated signals, and pilot signals of the present embodiment are spreading codes not modulated by data. The pilot signals are used for synchronization, carrier phase recovery, and for estimating the impulse response of the radio channel. Each SU includes a single pilot generator and at least one CDMA modulator and demodulator, together known as a CDMA modem. Each RCS 104, 105, 110 has a single pilot generator plus sufficient CDMA modulators and demodulators for all of the logical channels in use by all SUs.

The CDMA demodulator despreads the signal with appropriate processing to combat or exploit multipath propagation effects. Parameters concerning the received power level are used to generate the Automatic Power Control (AC) information which, in turn, is transmitted to the other end of the communication link. The AC information is used to control transmit power of the automatic forward power control (AFPC) and automatic reverse power control (ARPC) links. In addition, each RCS 104, 105 and 110 can perfonn Maintenance Power Control (MPC), in a manner similar to AC, to adjust the initial transmit power of each SU 111, 112, 115, 117 and 118. Demodulation is coherent where the pilot signal provides the phase reference.

The described radio links support multiple traffic channels with data rates of 8, 16, 32, 64, 128, and 144 kb/s. The physical channel to which a traffic channel is connected operates with a 64 k symbol/sec rate. Other data rates may be supported, and Forward Error Correction (FEC) coding can be employed. For the described embodiment, FEC with coding rate of ½ and constraint length 7 is used. Other rates and constraint lengths can be used consistent with the code generation techniques employed.

Diversity combining at the radio antennas of RCS 104, 105 and 110 is not necessary because CDMA has inherent frequency diversity due to the spread bandwidth. Receivers include Adaptive Matched Filters (AMFs) (not shown in FIG. 1) which combine the multipath signals. In the present embodiment, the exemplary AMFs perform Maximal Ratio Combining.

Referring to FIG. 1, RCS 104 interfaces to RDU 102 through links 131, 132, 137 with, for example, 1.544 Mb/s DS 1, 2.048 Mb/s E1; or HDSL Formats to receive and send digital data signals. While these are typical telephone company standardized interfaces, the present invention is not limited to these digital data formats only. The exemplary RCS line interface (not shown in FIG. 1) translates the line coding (such as HDB3, B8ZS, AMI) and extracts or produces framing information, performs Alarms and Facility signaling functions, as well as channel specific loop-back and parity check functions. The interfaces for this description provide 64 kb/s PCM encoded or 32 kb/s ADPCM encoded telephone traffic channels or ISDN channels to the RCS for processing. Other ADPCM encoding techniques can be used consistent with the sequence generation techniques.

The system of the present invention also supports bearer rate modification between the RCS 104 and each SU 111, 112, 115, 117 and 118 communicating with RCS 104 in which a CDMA message channel supporting 64 kb/s may be assigned to voiceband data or FAX when rates above 4.8 kb/s are present. Such 64 kb/s bearer channel is considered an unencoded channel. For ISDN, bearer rate modification may be done dynamically, based upon the D channel messages.

In FIG. 1, each SU 111, 112, 115, 117 and 118 either includes or interfaces with a telephone unit 170, or interfaces

with a local switch (PBX) 171. The input from the telephone unit may include voice, voiceband data and signaling. The SU translates the analog signals into digital sequences, and may also include a Data terminal 172 or an ISDN interface 173. The SU can differentiate voice input, voiceband data or FAX and digital data. The SU encodes voice data with techniques such as ADPCM at 32 kb/s or lower rates, and detects voiceband data or FAX with rates above 4.8 kb/s to modify the traffic channel (bearer rate modification) for unencoded transmission. Also, A-law, u-law, or no companding of the signal may be performed before transmission. For digital data, data compression techniques, such as idle flag removal, may also be used to conserve capacity and minimize interference.

The transmit power levels of the radio interface between RCS 104 and SUs 111, 112, 115, 117 and 118 are controlled using two different closed loop power control methods. The Automatic Forward Power Control (AFPC) method determines the Downlink transmit power level, and the Automatic Reverse Power Control (ARPC) method determines the Uplink transmit power level. The logical control channel by which SU 111 and RCS 104, for example, transfer power control information operates at least a 16 kHz update rate. Other embodiments may use a faster or slower update rate for example 64 kHz. These algorithms ensure that the transmit power of a user maintains an acceptable Bit-Error Rate (BER), maintains the system power at a minimum to conserve power, and maintains the power level of all SUs 111, 112, 115, 117 and 118 received by RCS 104 at a nearly equal level.

In addition, the system uses an optional maintenance power control method during the inactive mode of a SU. When SU 111 is inactive or powered-down to conserve power, the unit occasionally activates to adjust its initial transmit power level setting in response to a maintenance power control signal from RCS 104. The maintenance power signal is determined by the RCS 104 by measuring the received power level of SU 111 and present system power level and, from this, calculates the necessary initial transmit power. The method shortens the channel acquisition time of SU 111 to begin a communication. The method also prevents the transmit power level of SU 111 from becoming too high and interfering with other channels during the initial transmission before the closed loop power control reduces the transmit power.

RCS 104 obtains synchronization of its clock from an interface line such as, but not limited to, E1, T1, or HDSL interfaces. RCS 104 can also generate its own internal clock signal from an oscillator which may be regulated by a Global Positioning System (GPS) receiver. RCS 104 generates a Global Pilot Code, a channel with a spreading code but no data modulation, which can be acquired by remote SUs 111 through 118. All transmission channels of the RCS are synchronized to the Pilot channel, and spreading code phases of code generators (not shown) used for Logical communication channels within RCS 104 are also synchronized to the Pilot channel's spreading code phase. Similarly, SUs 111 through 118 which receive the Global Pilot Code of RCS 104 synchronize the spreading and de-spreading code phases of the code generators (not shown) of the SUs to the Global Pilot Code.

RCS 104, SU 111, and RDU 102 may incorporate system redundancy of system elements and automatic switching between internal functional system elements upon a failure event to prevent loss or drop-out of a radio link, power supply, traffic channel, or group of traffic channels.

Logical Communication Channels

A 'channel' of the prior art is usually regarded as a communications path which is part of an interface and which can be distinguished from other paths of that interface without regard to its content. However, in the case of CDMA, separate communications paths are distinguished only by their content. The term 'logical channel' is used to distinguish the separate data streams, which are logically equivalent to channels in the conventional sense. All logical channels and sub-channels of the present invention are mapped to a common 64 kilo-symbols per second (ksym/s) QPSK stream. Some channels are synchronized to associated pilot codes which are generated from, and perform a similar function to the system Global Pilot Code (GPC). The system pilot signals are not, however, considered logical channels.

Several logical communication channels are used over the RF communication link between the RCS and SU. Each logical communication channel either has a fixed, pre-determined spreading code or a dynamically assigned spreading code. For both pre-determined and assigned codes, the code phase is synchronized with the Pilot Code. Logical communication channels are divided into two groups: the Global Channel (GC) group includes channels which are either transmitted from the base station RCS to all remote SUs or from any SU to the RCS of the base station regardless of the SU's identity. The channels in the GC group may contain information of a given type for all users including those channels used by SUs to gain system access. Channels in the Assigned Channels (AC) group are those channels dedicated to communication between the RCS and a particular SU.

The Global Channels (GC) group provides for 1) Broadcast Control logical channels, which provide point to multipoint services for broadcasting messages to all SUs and paging messages to SUs; and 2) Access Control logical channels which provide point-to-point services on global channels for SUs to access the system and obtain assigned channels.

The RCS of the present invention has multiple Access Control logical channels, and one Broadcast Control group. An SU of the present invention has at least one Access Control channel and at least one Broadcast Control logical channel.

The Global logical channels controlled by the RCS are the Fast Broadcast Channel (FBCH) which broadcasts fast changing information concerning which services and which access channels are currently available, and the Slow Broadcast Channel (SBCH) which broadcasts slow changing system information and paging messages. The Access Channel (AXCH) is used by the SUs to access an RCS and gain access to assigned channels. Each AXCH is paired with a Control Channel (CTCH). The CTCH is used by the RCS to acknowledge and reply to access attempts by SUs. The Long Access Pilot (LAXPT) is transmitted synchronously with AXCH to provide the RCS with a time and phase reference.

An Assigned Channel (AC) group contains the logical channels that control a single telecommunication connection between the RCS and an SU. The functions developed when an AC group is formed include a pair of power control logical message channels for each of the Uplink and Downlink connections, and depending on the type of connection, one or more pairs of traffic channels. The Bearer Control function performs the required forward error control, bearer rate modification, and encryption functions.

Each SU 111, 112, 115, 117 and 118 has at least one AC group formed when a telecommunication connection exists, and each RCS 104, 105 and 110 has multiple AC groups formed, one for each connection in progress. An AC group

of logical channels is created for a connection upon successful establishment of the connection. The AC group includes encryption, FEC coding, and multiplexing on transmission, and FEC decoding, decryption and demultiplexing on reception.

Each AC group provides a set of connection oriented point-to-point services and operates in both directions between a specific RCS, for example, RCS 104 and a specific SU, for example, SU 111. An AC group formed for a connection can control more than one bearer over the RF communication channel associated with a single connection. Multiple bearers are used to carry distributed to data such as, but not limited to, ISDN. An AC group can provide for the duplication of traffic channels to facilitate switch over to 64 kb/s PCM for high speed facsimile and modem services for the bearer rate modification function.

The assigned logical channels formed upon a successful call connection and included in the AC group are a dedicated signaling channel [order wire (OW)], an AC channel, and one or more Traffic channels (TRCH) which are bearers of 8, 16, 32, pr 64 kb/s depending on the service supported. For voice traffic, moderate rate coded speech, ADPCM, or PCM can be supported on the Traffic channels. For ISDN service types, two 64 kb/s TRCHs form the B channels and a 16 kb/s TRCH forms the D channel. Alternatively, the AC subchannel may either be separately modulated on its own CDMA channel, or may be time division multiplexed with a traffic channel or OW channel.

Each SU 111, 112, 115, 117 and 118 of the present invention supports up to three simultaneous traffic channels. The mapping of the three logical channels for TRCHs to the user data is shown below in Table 1:

TABLE 1

Mapping of service types to the three available TRCH channels

Service	TRCH(0)	TRCH(1)	TRCH(2)
16 kb/s POTS	TRCH/16	not used	not used
32 + 64 kb/s POTS (during BCM)	TRCH/32	TRCH/64	not used
32 kb/s POTS	TRCH/32	not used	not used
64 kb/s POTS	not used	TRCH/64	not used
ISDN D	not used	not used	TRCH/16
ISDN B + D	TRCH/64	not used	TRCH/16
ISDN 2B + D	TRCH/64	TRCH/64	TRCH/16
Digital LL @ 64 kb/s	TRCH/64	not used	not used
Digital LL @ 2 × 64 kb/s	TRCH/64	TRCH/64	not used
Analog LL @ 64 kb/s	TRCH/64	not used	not used

The AC data rate is sent at 64 kb/s. The AC logical channel is not FEC coded to avoid delay and is transmitted at a relatively low power level to minimize capacity used for AC. Alternatively, the AC and OW may be separately modulated using complex spreading code sequences, or they may be time division multilplexed.

The OW logical channel is FEC coded with a rate ½ convolutional code. This logical channel is transmitted in bursts when signaling data is present to reduce interference. After an idle period, the OW signal begins with at least 35 symbols prior to the start of the data frame. For silent maintenance call data, the OW is transmitted continuously between frames of data. Table 2 summarizes the logical channels used in the exemplary embodiment:

TABLE 2

Logical Channels and sub-channels of the B-CDMA Air Interface

Channel name	Abbr.	Brief Description	Direction (forward or reverse)	Bit rate	Max BER	Power level	Pilot
Global Channels							
Fast Broadcast Channel	FBCH	Broadcasts fast-changing system information	F	16 kb/s	1e-4	Fixed	GLPT
Slow Broadcast Channel	SBCH	Broadcasts paging messages to FSUs and slow-changing system information	F	16 kb/s	1e-7	Fixed	GLPT
Access Channels	AXCH(i)	For initial access attempts by FSUs	R	32 kb/s	1e-7	Controlled by APC	LAXPT(i)
Control Channels	CTCH(i)	For granting access	F	32 kb/s	1e-7	Fixed	GLPT
Assigned Channels							
16 kb/s POTS	TRCH/16	General POTS use	F/R	16 kb/s	1e-4	Controlled by APC	F-GLPT R-ASPT
32 kb/s POTS	TRCH/32	General POTS use	F/R	32 kb/s	1e-4	Controlled by APC	F-GLPT R-ASPT
64 kb/s POTS	TRCH/64	POTS use for in-band modems/fax	F/R	64 kb/s	1e-4	Controlled by APC	F-GLPT R-ASPT
D channel	TRCH/16	ISDN D channel	F/R	16 kb/s	1e-7	Controlled by APC	F-GLPT R-ASPT
Order	OW	assigned	F/R	32	1e-7	Controlled	F-GLPT

TABLE 2-continued

Logical Channels and sub-channels of the B-CDMA Air Interface

Channel name	Abbr.	Brief Description	Direction (forward or reverse)	Bit rate	Max BER	Power level	Pilot
wire channel		signaling channel		kb/s		by APC	R-ASPT
APC channel	APC	carries APC commands	F/R	64 kb/s	2e-1	Controlled by APC	F-GLPT R-ASPT

The Spreading Codes

The CDMA code generators used to encode the logical channels of the present invention employ Linear Shift Registers (LSRs) with feedback logic which is a method well known in the art. The code generators of the present embodiment of the invention generate 64 synchronous unique sequences. Each RF communication channel uses a pair of these sequences for complex spreading (in-phase and quadrature) of the logical channels, so the generator gives 32 complex spreading sequences. The sequences are generated by a single seed which is initially loaded into a shift register circuit.

The Generation of Spreading Code Sequences and Seed Selection

The spreading code period of the present invention is defined as an integer multiple of the symbol duration, and the beginning of the code period is also the beginning of the symbol. The relation between bandwidths and the symbol lengths chosen for the exemplary embodiment of the present invention is:

BW (MHZ)	L(chips/symbol)
7	91
10	130
10.5	133
14	182
15	195

The spreading code length is also a multiple of 64 and of 96 for ISDN frame support. The spreading code is a sequence of symbols, called chips or chip values. The general methods of generating pseudorandom sequences using Galois Field mathematics is known to those skilled in the art; however, a unique set, or family, of code sequences has been derived for the present invention. First, the length of the linear feedback shift register to generate a code sequence is chosen, and the initial value of the register is called a "seed". Second, the constraint is imposed that no code sequence generated by a code seed may be a cyclic shift of another code sequence generated by the same code seed. Finally, no code sequence generated from one seed may be a cyclic shift of a code sequence generated by another seed.

It has been determined that the spreading code length of chip values of the present invention is:

$$128\times233415=29877120 \tag{1}$$

The spreading codes are generated by combining a linear sequence of period 233415 and a nonlinear sequence of period 128

The FBCH channel of the exemplary embodiment is an exception because it is not coded with the 128 length sequence, so the FBCH channel spreading code has period 233415.

The nonlinear sequence of length 128 is implemented as a fixed sequence loaded into a shift register with a feed-back connection. The fixed sequence can be generated by an m-sequence of length 127 padded with an extra logic 0, 1, or random value as is well known in the art.

The linear sequence of length L=233415 is generated using a linear feedback shift register (LFSR) circuit with 36 stages. The feedback connections correspond to a irreducible polynomial h(n) of degree 36. The polynomial h(x) chosen for the exemplary embodiment of the present invention is

$$h(x)=x^{36}+x^{35}+x^{30}+x^{28}+x^{26}+x^{25}+x^{22}+x^{20}+x^{19}+x^{17}+x^{16}+x^{15}+x^{14}+x^{12}+x^{11}+x^{9}+x^{8}+x^{4}+x^{3}+x^{2}+1$$

or, in binary notation

$$h(x)=(1100001010110010110111101101100011101) \tag{2}$$

A group of "seed" values for a LFSR representing the polynomial h(x) of equation (2) which generates code sequences that are nearly orthogonal with each other is determined. The first requirement of the seed values is that the seed values do not generate two code sequences which are simply cyclic shifts of each other.

The seeds are represented as elements of $GF(2^{36})$ which is the field of residue classes modulo h(x). This field has a primitive element $\delta=x^2+x+1$. The binary representation of δ is

$$\delta=000000000000000000000000000000000111 \tag{3}$$

Every element of $GF(2^{36})$ can also be written as a power of δ reduced modulo h(x). Consequently, the seeds are represented as powers of δ, the primitive element.

The solution for the order of an element does not require a search of all values; the order of an element divides the order of the field $(GF(2^{36}))$. When δ is any element of $GF(2^{36})$ with

$$x^e\equiv1 \tag{4}$$

for some e, then $e|2^{36}-1$. Therefore, the order of any element in $GF(2^{36})$ divides $2^{36}-1$.

Using these constraints, it has been determined that a numerical search generates a group of seed values, n, which are powers of δ, the primitive element of h(x).

The present invention includes a method to increase the number of available seeds for use in a CDMA communication system by recognizing that certain cyclic shifts of the previously determined code sequences may be used simul-

taneously. The round trip delay for the cell sizes and bandwidths of the present invention are less than 3000 chips. In one embodiment of the present invention, sufficiently separated cyclic shifts of a sequence can be used within the same cell without causing ambiguity for a receiver attempting to determine the code sequence. This method enlarges the set of sequences available for use.

By implementing the tests previously described, a total of 3879 primary seeds were determined through numerical computation. These seeds are given mathematically as

$$\delta^n \text{modulo } h(x) \tag{5}$$

where 3879 values of n are listed in the Appendix A, with δ=(00, . . . 00111) as before in (3).

When all primary seeds are known, all secondary seeds of the present invention are derived from the primary seeds by shifting them multiples of 4095 chips modulo h(x). Once a family of seed values is determined, these values are stored in memory and assigned to logical channels as necessary. Once assigned, the initial seed value is simply loaded into LFSR to produce the required spreading code sequence associated with the seed value.

Rapid Acquisition Feature of Long and Short Codes.

Rapid acquisition of the correct code phase by a spread-spectrum receiver is improved by designing spreading codes which are faster to detect. The present embodiment of the invention includes a new method of generating code sequences that have rapid acquisition properties by using one or more of the following methods. First, a long code may be constructed from two or more short codes. The new implementation uses many code sequences, one or more of which are rapid acquisition sequences of length L that have average acquisition phase searches r=log 2L. Sequences with such properties are well known to those practiced in the art. The average number of acquisition test phases of the resulting long sequence is a multiple of r=log 2L rather than half of the number of phases of the long sequence.

Second, a method of transmitting complex valued spreading code sequences (In-phase (I) and Quadrature (Q) sequences) in a pilot spreading code signal may be used rather than transmitting real valued sequences. Two or more separate code sequences may be transmitted over the complex channels. If the sequences have different phases, an acquisition may be done by acquisition circuits in parallel over the different code sequences when the relative phase shift between the two or more code channels is known. For example, for two sequences, one can be sent on an In phase (I) channel and one on the Quadrature (Q) channel. To search the code sequences, the acquisition detection means searches the two channels, but begins the (Q) channel with an offset equal to one-half of the spreading code sequence length. With code sequence length of N, the acquisition means starts the search at N/2 on the (Q) channel. The average number of tests to find acquisition is N/2 for a single code search, but searching the (I) and phase delayed (Q) channel in parallel reduces the average number of tests to N/4. The codes sent on each channel could be the same code, the same code with one channel's code phase delayed, or different code sequences.

Epoch and Sub-epoch Structures

The long complex spreading codes used for the exemplary system of the present invention have a number of chips after which the code repeats. The repetition period of the spreading sequence is called an epoch. To map the logical channels to CDMA spreading codes, the present invention uses an Epoch and Sub-epoch structure. The code period for the CDMA spreading code to modulate logical channels is 29877120 chips/code period which is the same number of chips for all bandwidths. The code period is the epoch of the present invention, and Table 3 below defines the epoch duration for the supported chip rates. In addition, two subdepochs are defined over the spreading code epoch and are 233415 chips and 128 chips long.

The 233415 chip sub-epoch is referred to as a long sub-epoch, and is used for synchronizing events on the RF communication interface such as encryption key switching and changing from global to assigned codes. The 128 chip short epoch is defined for use as an additional timing reference. The highest symbol rate used with a single CDMA code is 64 ksym/s. There is always an integer number of chips in a symbol duration for the supported symbol rates 64, 32, 16, and 8 ksym/s.

TABLE 3

Bandwidths, Chip Rates, and Epochs

Bandwidth (MHz)	Chip Rate, CompTex (Mchip/sec)	number of chips in a 64 kbit/sec symbol	128 chip sub-epoch duration* (µs)	233415 chip sub-epoch duration* (ms)	Epoch duration (sec)
7	5.824	91	21.978	40.078	5.130
10	8.320	130	15.385	28.055	3.591
10.5	8.512	133	15.038	27.422	3.510
14	11.648	182	10.989	20.039	2.565
15	12.480	195	10.256	18.703	2.394

*numbers in these columns are rounded to 5 digits.

Mapping of the Logical Channels to Epochs and Sub-epochs

The complex spreading codes are designed such that the beginning of the sequence epoch coincides with the beginning of a symbol for all of the bandwidths supported. The present invention supports bandwidths of 7, 10, 10.5, 14, and 15 MHz. Assuming nominal 20% roll-off, these bandwidths correspond to the following chip rates in Table 4.

TABLE 4

Supported Bandwidths and Chip Rates for CDMA.

BW (MHz)	R_c (Complex Mchips/sec)	Excess BW, %	L: (R_c/L) = 64 k	Factorization of L
7	5.824	20.19	91	7 × 13
10	8.320	20.19	130	2 × 5 × 13
10.5	8.512	23.36	133	7 × 19
14	11.648	20.19	182	2 × 7 × 13
15	12.480	20.19	195	3 × 5 × 13

The number of chips in an epoch is:

$$N=29877120=2^7\times3^3\times5\times7\times13\times19 \tag{6}$$

If interleaving is used, the beginning of an interleaver period coincides with the beginning of the sequence epoch. The spreading sequences generated using the method of the present invention can support interleaver periods that are multiples of 1.5 ms for various bandwidths.

Cyclic sequences of the prior art are generated using linear feedback shift register (LFSR) circuits. However, this method does not generate sequences of even length. One

embodiment of the spreading code sequence generator using the code seeds generated previously is shown in FIG. 2*a*, FIG. 2*b*, and FIG. 2*c*. The present invention uses a 36 stage LFSR **201** to generate a sequence of period $N'=233415=3^3\times 5\times 7\times 13\times 19$, which is C_O in FIG. 2*a*. In FIGS. 2*a*, 2*b*, and 2*c*, the symbol $\oplus$ represents a binary addition (EXCLUSIVE-OR). A sequence generator designed as above generates the in-phase and quadrature parts of a set of complex sequences. The tap connections and initial state of the 36 stage LFSR determine the sequence generated by this circuit. The tap coefficients of the 36 stage LFSR are determined such that the resulting sequences have the period 233415. Note that the tap connections shown in FIG. 2*a* correspond to the polynomial given in equation (2). Each resulting sequence is then overlaid by binary addition with the 128 length sequence C* to obtain the epoch period 29877120.

FIG. 2*b* shows a Feed Forward (FF) circuit **202** which is used in the code generator. The signal X[n−1] is output of the chip delay **211**, and the input of the chip delay **211** is X[n]. The code chip C[n] is formed by the logical adder **212** from the input X[n] and X[n−1]. FIG. 2*c* shows the complete spreading code generator. From the LFSR **201**, output signals go through a chain of up to 63 single stage FFs **203** cascaded as shown. The output of each FF is overlaid with the short, even code sequence C * period $128=2^7$ which is stored in code memory **222** and which exhibits spectral characteristics of a pseudorandom sequence to obtain the epoch N=29877120. This sequence of 128 is determined by using an m-sequence (PN sequence) of length $127=2^7-1$ and adding a bit-value, such as logic 0, to the sequence to increase the length to 128 chips. The even code sequence C * is input to the even code shift register **221**, which is a cyclic register, that continually outputs the sequence. The short sequence is then combined with the long sequence using an EXCLUSIVE-OR operation **213**, **214**, **220**.

As shown in FIG. 2*c*,up to 63 spreading code sequences C_O through C_{63} are generated by tapping the output signals of FFs **203** and logically adding the short sequence C* in binary adders **213**, **214**, and **220**, for example. One skilled in the art would realize that the implementation of FF **203** will create a cumulative delay effect for the code sequences produced at each FF stage in the chain. This delay is due to the nonzero electrical delay in the electronic components of the implementation. The timing problems associated with the delay can be mitigated by inserting additional delay elements into the FF chain in one version of the embodiment of the invention. The FF chain of FIG. 2*c* with additional delay elements is shown in FIG. 2*d*.

The code-generators in the exemplary embodiment of the present invention are configured to generate either global codes, or assigned codes. Global codes are CDMA codes that can be received or transmitted by all users of the system. Assigned codes are CDMA codes that are allocated for a particular connection. When a set of sequences are generated from the same generator as described, only the seed of the 36 stage LFSR is specified to generate a family of sequences. Sequences for all the global codes, are generated using the same LFSR circuit. Therefore, once an SU has synchronized to the Global pilot signal from an RCS and knows the seed for the LFSR circuit for the Global Channel codes, it can generate not only the pilot sequence but also all other global codes used by the RCS.

The signal that is upconverted to RF is generated as follows. The output signals of the above shift register circuits are converted to an antipodal sequence (0 maps into +1, 1 maps into −1). The Logical channels are initially converted to QPSK signals, which are mapped as constellation points as is well known in the art. The In-phase and Quadrature channels of each QPSK signal form the real and imaginary parts of the complex data value. Similarly, two spreading codes are used to form complex spreading chip values. The complex data are spread by being multiplied by the complex spreading code. Similarly, the received complex data is correlated with the conjugate of the complex spreading code to recover despread data.

Short Codes

Short codes are used for the initial ramp-up process when an SU accesses an RCS. The period of the short codes is equal to the symbol duration and the start of each period is aligned with a symbol boundary. Both SU and RCS derive the real and imaginary parts of the short codes from the last eight feed-forward sections of the sequence generator producing the global codes for that cell.

The short codes that are in use in the exemplary embodiment of the invention are updated every 3 ms. Other update times that are consistent with the symbol rate may be used. Therefore, a change-over occurs every 3 ms starting from the epoch boundary. At a change-over, the next symbol length portion of the corresponding feed-forward output becomes the short code. When the SU needs to use a particular short code, it waits until the first 3 ms boundary of the next epoch and stores the next symbol length portion output from the corresponding FF section. This shall be used as the short code until the next change-over, which occurs 3 ms later.

The signals represented by these short codes are known as Short Access Channel pilots (SAXPTs).

Mapping of Logical Channels to Spreading Codes

The exact relationship between the spreading code sequences and the CDMA logical channels and pilot signals is documented in Table 5a and Table 5b. Those signal names ending in '-CH' correspond to logical channels. Those signal names ending in '-PT' correspond to pilot signals, which are described in detail below.

TABLE 5a

Spreading code sequences and global CDMA codes

Sequence	Quadrature	Logical Channel or Pilot Signal	Direction
C_0	I	FPCH	Forward (F)
C_1	Q	FBCH	F
$C_2 \oplus C^*$	I	GLPT	F
$C_3 \oplus C^*$	Q	GLPT	F
$C_4 \oplus C^*$	I	SBCH	F
$C_5 \oplus C^*$	Q	SBCH	F
$C_6 \oplus C^*$	I	CTCH(0)	F
$C_7 \oplus C^*$	Q	CTCH (0)	F
$C_8 \oplus C^*$	I	APCH (1)	F
$C_9 \oplus C^*$	Q	APCH (1)	F
$C_{10} \oplus C^*$	I	CTCH (1)	F
$C_{11} \oplus C^*$	Q	CTCH(1)	F
$C_{12} \oplus C^*$	I	APCH(1)	F
$C_{13} \oplus C^*$	Q	APCH (1)	F
$C_{14} \oplus C^*$	I	CTCH (2)	F
$C_{15} \oplus C^*$	Q	CTCH (2)	F
$C_{16} \oplus C^*$	I	APCH (2)	F
$C_{17} \oplus C^*$	Q	APCH (2)	F
$C_{18} \oplus C^*$	I	CTCH (3)	F
$C_{19} \oplus C^*$	Q	CTCH (3)	F
$C_{20} \oplus C^*$	I	APCH (3)	F
$C_{21} \oplus C^*$	Q	APCH (3)	F
$C_{22} \oplus C^*$	I	reserved	—

TABLE 5a-continued

Spreading code sequences and global CDMA codes

Sequence	Quadrature	Logical Channel or Pilot Signal	Direction
$C_{23}\oplus C^*$	Q	reserved	—
. . .	. . .	. . .	. . .
. . .	. . .	. . .	. . .
$C_{40}\oplus C^*$	I	reserved	—
$C_{41}\oplus C^*$	Q	reserved	—
$C_{42}\oplus C^*$	I	AXCH(3)	Reverse (R)
$C_{43}\oplus C^*$	Q	AXCH(3)	R
$C_{44}\oplus C^*$	I	LAXPT(3) SAXPT(3) seed	R
$C_{45}\oplus C^*$	Q	LAXPT(3) SAXPT(3) seed	R
$C_{46}\oplus C^*$	I	AXCH(2)	R
$C_{47}\oplus C^*$	Q	AXCH(2)	R
$C_{48}\oplus C^*$	I	LAXPT(2) SAXPT(2) seed	R
$C_{49}\oplus C^*$	Q	LAXPT(2) SAXPT(2) seed	R
$C_{50}\oplus C^*$	I	AXCH(1)	R
$C_{51}\oplus C^*$	Q	AXCH(1)	R
$C_{52}\oplus C^*$	I	LAXPT(1) SAXPT(1) seed	R
$C_{53}\oplus C^*$	Q	LAXPT(1) SAXPT(1) seed	R
$C_{54}\oplus C^*$	I	AXCH(0)	R
$C_{55}\oplus C^*$	Q	AXCH(0)	R
$C_{56}\oplus[00ab]C^*$	I	LAXPT(0) SAXPT(0) seed	R
$C_{57}\oplus C^*$	Q	LAXPT(0) SAXPT(0) seed	R
$C_{58}\oplus C^*$	I	IDLE	—
$C_{59}\oplus C^*$	Q	IDLE	—
$C_{60}\oplus C^*$	I	AUX	R
$C_{61}\oplus C^*$	Q	AUX	R
$C_{62}\oplus C^*$	I	reserved	—
$C_{63}\oplus C^*$	Q	reserved	—

TABLE 5b

Spreading code sequences and assigned CDMA codes.

Sequence	Quadrature	Logical Channel or Pilot Signal	Direction
$C_0\oplus C^*$	I	ASPT	Reverse (R)
$C_1\oplus C^*$	Q	ASPT	R
$C_2\oplus C^*$	I	APCH	R
$C_3\oplus C^*$	Q	APCH	R
$C_4\oplus C^*$	I	OWCH	R
$C_5\oplus C^*$	Q	OWCH	R
$C_6\oplus C^*$	I	TRCH(0)	R
$C_7\oplus C^*$	Q	TRCH(0)	R
$C_8\oplus C^*$	I	TRCH(1)	R
$C_9\oplus C^*$	Q	TRCH(1)	R
$C_{10}\oplus C^*$	I	TRCH(2)	R
$C_{11}\oplus C^*$	Q	TRCH(2)	R
$C_{12}\oplus C^*$	I	TRCH(3)	R
$C_{13}\oplus C^*$	Q	TRCH(3)	R
$C_{14}\oplus C^*$	I	reserved	—
$C_{15}\oplus C^*$	Q	reserved	—
. . .	. . .	. . .	. . .
. . .	. . .	. . .	. . .
$C_{44}\oplus C^*$	I	reserved	—
$C_{45}\oplus C^*$	Q	reserved	—
$C_{46}\oplus C^*$	I	TRCH(3)	Forward (F)
$C_{47}\oplus C^*$	Q	TRCH(3)	F
$C_{48}\oplus C^*$	I	*TRCH(2)	F
$C_{49}\oplus C^*$	Q	TRCH(2)	F
$C_{50}\oplus C^*$	I	TRCH(1)	F
$C_{51}\oplus C^*$	Q	TRCH(1)	F
$C_{52}\oplus C^*$	I	TRCH(0)	F
$C_{53}\oplus C^*$	Q	TRCH(0)	F

TABLE 5b-continued

Spreading code sequences and assigned CDMA codes.

Sequence	Quadrature	Logical Channel or Pilot Signal	Direction
$C_{54}\oplus C^*$	I	OWCH	F
$C_{55}\oplus C^*$	Q	OWCH	F
$C_{56}\oplus C^*$	I	APCH	F
$C_{57}\oplus C^*$	Q	APCH	F
$C_{58}\oplus C^*$	I	IDLE	—
$C_{59}\oplus C^*$	Q	IDLE	—
$C_{60}\oplus C^*$	I	reserved	—
$C_{61}\oplus C^*$	Q	reserved	—
$C_{62}\oplus C^*$	I	reserved	—
$C_{63}\oplus C^*$	Q	reserved	—

For global codes, the seed values for the 36 bit shift register are chosen to avoid using the same code, or any cyclic shift of the same code, within the same geographical area to prevent ambiguity or harmful interference. No assigned code is equal to, or a cyclic shift of a global code.

Pilot Signals

The pilot signals are used for synchronization, carrier phase recovery, and for estimating the impulse response of the radio channel.

The RCS **104** transmits a forward link pilot carrier reference as a complex pilot code sequence to provide time and phase reference for all SUs **111**, **112**, **115**, **117** and **118** in its service area. The power level of the Global Pilot (GLPT) signal is set to provide adequate coverage over the whole RCS service area, which area depends on the cell size. With only one pilot signal in the forward link, the reduction in system capacity due to the pilot energy is negligible.

The SUs **111**, **112**, **115**, **117** and **118** each transmits a pilot carrier reference as a quadrature modulated (complex-valued) pilot spreading code sequence to provide a time and phase reference to the RCS for the reverse link. The pilot signal transmitted by the SU of one embodiment of the invention is 6 dB lower than the power of the 32 kb/s POTS traffic channel. The reverse pilot channel is subject to APC. The reverse link pilot associated with a particular connection is called the Assigned Pilot (ASPT). In addition, there are pilot signals associated with access channels. These are called the Long Access Channel Pilots (LAXPTs). Short access channel pilots (SAXPTs) are also associated with the access channels and used for spreading code acquisition and initial power ramp-up

All pilot signals are formed from complex codes, as defined below:

$$\text{GLPT (forward)}=\{C_2\oplus C^*)+j\cdot(C_3\oplus C^*)\}\cdot\{(1)+j\cdot(0)\}$$
$$\{\text{Complex Code}\}\cdot\{\text{Carrier}\}$$

The complex pilot signals are de-spread by multiplication with conjugate spreading codes: $\{(C_2\oplus C^*)-j\cdot(C_3\oplus C^*)\}$. By contrast, traffic channels are of the form:

$$TRCH_n(\text{forward/reverse}) = \{(C_k\oplus C^*) + j\cdot(C_l\oplus C^*)\}\cdot\{(\pm1)+j(\pm1)\}\ \{\text{Complex Codes}\}\cdot\{\text{Data Symbol}\}$$

which thus form a constellation set at $\pi/4$ radians with respect to the pilot signal constellations.

The GLPT constellation is shown in FIG. 3*a*, and the $TRCH_n$ traffic channel constellation is shown in FIG. 3*b*.

Logical Channel Assignment of the FBCH, SBCH, and Traffic Channels

The FBCH is a global forward link channel used to broadcast dynamic information about the availability of

services and AXCHs. Messages are sent continuously over this channel, and each message lasts approximately 1 ms. The FBCH message is 16 bits long, repeated continuously, and is epoch aligned. The FBCH is formatted as defined in Table 6.

TABLE 6

FBCH format

Bit	Definition
0	Traffic Light 0
1	Traffic Light 1
2	Traffic Light 2
3	Traffic Light 3
4–7	service indicator bits
8	Traffic Light 0
9	Traffic Light 1
10	Traffic Light 2
11	Traffic Light 3
12–15	service indicator bits

For the FBCH, bit 0 is transmitted first. As used in Table 6, a traffic light corresponds to an Access Channel (AXCH) and indicates whether the particular access channel is currently in use (a red) or not in use (a green). A logic '1' indicates that the traffic light is green, and a logic '0' indicates the traffic light is red. The values of the traffic light bits may change from octet to octet, and each 16 bit message contains distinct service indicator bits which describe the types of services that are available for the AXCHs.

One embodiment of the present invention uses service indicator bits as follows to indicate the availability of services or AXCHs. The service indicator bits {4,5,6,7,12, 13,14,15} taken together may be an unsigned binary number, with bit 4 as the MSB and bit 15 as the LSB. Each service type increment has an associated nominal measure of the capacity required, and the FBCH continuously broadcasts the available capacity. This is scaled to have a maximum value equivalent to the largest single service increment possible. When an SU requires a new service or an increase in the number of bearers, it compares the capacity required to that indicated by the FBCH, and then considers itself blocked if the capacity is not available. The FBCH and the traffic channels are aligned to the epoch.

Slow Broadcast Information frames contain system or other general information that is available to all SUs and Paging Information frames contain information about call requests for particular SUs. Slow Broadcast Information frames and Paging Information frames are multiplexed together on a single logical channel which forms the Slow Broadcast Channel (SBCH). As previously defined, the code epoch is a sequence of 29 877 20 chips having an epoch duration which is a function of the chip rate defined in Table 7 below. In order to facilitate power saving, the channel is divided into N "Sleep" Cycles, and each Cycle is subdivided into M Slots, which are 19 ms long, except for 10.5 Mhz bandwidth which has slots of 18 ms.

TABLE 7

SBCH Channel Format Outline

Bandwidth (MHz)	Spreading Code Rate (MHz)	Epoch Length (ms)	Cycles/ Epoch N	Cycle Length (ms)	Slots/ Cycle M	Slot Length (ms)
7.0	5.824	5130	5	1026	54	19
10.0	8.320	3591	3	1197	63	19
10.5	8.512	3510	3	1170	65	18

TABLE 7-continued

SBCH Channel Format Outline

Bandwidth (MHz)	Spreading Code Rate (MHz)	Epoch Length (ms)	Cycles/ Epoch N	Cycle Length (ms)	Slots/ Cycle M	Slot Length (ms)
14.0	11.648	2565	3	855	45	19
15.0	12.480	2394	2	1197	63	19

Sleep Cycle Slot #1 is always used for slow broadcast information. Slots #2 to #M-1 are used for paging groups unless extended slow broadcast information is inserted. The pattern of cycles and slots in one embodiment of the present invention run continuously at 16 kb/s.

Within each Sleep Cycle the SU powers-up the receiver and re-acquires the pilot code. It then achieves carrier lock to a sufficient precision for satisfactory demodulation and Viterbi decoding. The settling time to achieve carrier lock may be up to 3 Slots in duration. For example, an SU assigned to Slot #7 powers up the Receiver at the start of Slot #4. Having monitored its Slot the SU will have either recognized its Paging Address and initiated an access request, or failed to recognize its Paging Address in which case it reverts to the Sleep mode. Table 8 shows duty cycles for the different bandwidths, assuming a wake-up duration of 3 Slots.

TABLE 8

Sleep-Cycle Power Saving

Bandwidth (MHz)	Slots/Cycle	Duty Cycle
7.0	54	7.4%
10.0	63	6.3%
10.5	65	6.2%
14.0	45	8.9%
15.0	63	6.3%

Spreading Code Tracking and AMF Detection in Multipath Channels

Spreading Code Tracking

Three CDMA spreading code tracking methods in multipath fading environments are described which track the code phase of a received multipath spread-spectrum signal. The first is the prior art tracking circuit which simply tracks the spreading code phase with the highest detector output signal value, the second is a tracking circuit that tracks the median value of the code phase of the group of multipath signals, and the third is the centroid tracking circuit which tracks the code-phase of an optimized, least mean squared weighted average of the multipath signal components. The following describes the algorithms by which the spreading code phase of the received CDMA signal is tracked.

A tracking circuit has operating characteristics that reveal the relationship between the time error and the control voltage that drives a Voltage Controlled Oscillator (VCO) of a spreading code phase tracking circuit. When there is a positive timing error, the tracking circuit generates a negative control voltage to offset the timing error. When there is a negative timing error, the tracking circuit generates a positive control voltage to offset the timing error. When the tracking circuit generates a zero value, this value corresponds to the perfect time alignment called the 'lock-point'.

FIG. 3 shows the basic tracking circuit. Received signal r(t) is applied to matched filter **301**, which correlates r(t) with a local code-sequence c(t) generated by Code Generator **303**. The output signal of the matched filter x(t) is sampled at the sampler **302** to produce samples x[nT] and x[nT+T/2]. The samples x[nT] and x[nT+T/2] are used by a tracking circuit **304** to determine if the phase of the spreading code c(t) of the code generator **303** is correct. The tracking circuit **304** produces an error signal e(t) as an input to the code generator **303**. The code generator **303** uses this signal e(t) as an input signal to adjust the code-phase it generates.

In a CDMA system, the signal transmitted by the reference user is written in the low-pass representation as

$$s(t)=\sum_{k=-\infty}^{\infty} c_k P_{Tc}(t-kT_c) \tag{7}$$

where c_k represents the spreading code coefficients, $P_{Tc}(t)$ represents the spreading code chip waveform, and T_c is the chip duration. Assuming that the reference user is not transmitting data so that only the spreading code modulates the carrier. Referring to FIG. 3*c*, the received signal is

$$r(t)=\sum_{i=1}^{M} a_i s(t-\tau_i) \tag{8}$$

Here, a_i is due to fading effect of the multipath channel on the i-th path and τ_i is the random time delay associated with the same path. The receiver passes the received signal through a matched filter, which is implemented as a correlation receiver and is described below. This operation is done in two steps: first the signal is passed through a chip matched filter and sampled to recover the spreading code chip values, then this chip sequence is correlated with the locally generated code sequence.

FIG. 3*c* shows the chip matched filter **301**, matched to the chip waveform $P_{Tc}(t)$, and the sampler **302**. Ideally, the signal x(t) at the output terminal of the chip matched filter is

$$x(t)=\sum_{i=k}^{M}\sum_{k=-\infty}^{\infty} a_i c_k g(t-\tau_i-kT_c) \tag{9}$$

where

$$g(t)=P_{Tc}(t)*h_R(t) \tag{10}$$

Here, $h_R(t)$ is the impulse response of the chip matched filter and '*' denotes convolution. The order of the summations can be rewritten as

$$x(t)=\sum_{k=-\infty}^{\infty} c_k f(t-kT_c) \tag{11}$$

where

$$f(t)=\sum_{i=1}^{M} a_i g(t-\tau_i) \tag{12}$$

In the multipath channel described above, the sampler samples the output signal of the matched filter to produce x(nT) at the maximum power level points of g(t). In practice, however, the waveform g(t) is severely distorted because of the effect of the multipath signal reception, and a perfect time alignment of the signals is not available.

When the multipath distortion in the channel is negligible and a perfect estimate of the timing is available, i.e., $a_1=1$, $\tau_1=0$, and $a_i=0$, i=2, . . . , M, the received signal is r(t)=s(t). Then, with this ideal channel model, the output of the chip matched filter becomes

$$x(t)=\sum_{k=-\infty}^{\infty} c_k g(t-kT_c) \tag{13}$$

When there is multipath fading, however, the received spreading code chip value waveform is distorted, and has a number of local maxima that can change from one sampling interval to another depending on the channel characteristics.

For multipath fading channels with quickly changing channel characteristics, it is not practical to try to locate the maximum of the waveform f(t) in every chip period interval. Instead, a time reference may be obtained from the characteristics of f(t) that may not change as quickly. Three tracking methods are described based on different characteristics of f(t).

Prior Art Spreading Code Tracking Method:

Prior art tracking methods include a code tracking circuit in which the receiver attempts to determine the timing of the maximum matched filter output value of the chip waveform occurs and sample the signal accordingly. However, in multipath fading channels, the receiver despread code waveform can have a number of local maxima, especially in a mobile environment. In the following, f(t) represents the received signal waveform of the spreading code chip convolved with the channel impulse response. The frequency response characteristic of f(t) and the maximum of this characteristic can change rather quickly making it impractical to track the maximum of f(t).

Define τ to be the time estimate that the tracking circuit calculates during a particular sampling interval. Also, define the following error function

$$\epsilon=\begin{cases}\displaystyle\int_{\{t:|\tau-t|>\delta\}} f(t)dt, & |\tau-t|>\delta\\ \epsilon=0 & |\tau-t|<\delta\end{cases} \tag{14}$$

The tracking circuits of the prior art calculate a value of the input signal that minimizes the error ε. One can write

$$\min\epsilon=1-\max_{\tau}\int_{\tau-\delta}^{\tau+\delta} f(t)dt \tag{15}$$

Assuming f(τ) has a smooth shape in the values given, the value of τ for which f(τ) is maximum minimizes the error ε, so the tracking circuit tracks the maximum point of f(t).

Median Weighted Value Tracking Method:

The Median Weighted Tracking Method of one embodiment of the present invention, minimizes the absolute weighted error, defined as

$$\epsilon=\int_{-\infty}^{\infty}|t-\tau|f(t)dt \tag{16}$$

This tracking method calculates the 'median' signal value of f(t) by collecting information from all paths, where f(τ) is as in equation 12. In a multipath fading environment, the waveform f(t) can have multiple local maxima, but only one median.

To minimize ε, take the derivative of equation (16) is taken with respect to τ and the result is equated to zero, which gives

$$\int_{-\infty}^{\tau} f(t)dt = \int_{\tau}^{\infty} f(t)dt \tag{17}$$

The value of τ that satisfies (17) is called the 'median' of f(t). Therefore, the Median Tracking Method of the present embodiment tracks the median of f(t). FIG. 4 shows an implementation of the tracking circuit based on minimizing the absolute weighted error defined above. The signal x(t) and its one-half chip offset version x(t+T/2) are sampled by the A/D **401** at a rate 1/T. The following equation determines the operating characteristic of the circuit in FIG. 4:

$$\epsilon(\tau) = \sum_{n=1}^{2L} |f(\tau - nT/2)| - |f(\tau + nT/2)| \tag{18}$$

Tracking the median of a group of multipath signals keeps the received energy of the multipath signal components substantially equal on the early and late sides of the median point of the correct locally generated spreading code phase c_n. The tracking circuit consists of an A/D **401** which samples an input signal x(t) to form the half-chip offset samples. The half chip offset samples are alternatively grouped into even samples called an early set of samples $x(nT+\tau)$ and odd samples called a late set of samples $x(nT+(T/2)+\tau)$. The first correlation bank adaptive matched filter **402** multiplies each early sample by the spreading code phases c(n+1), c(n+2), . . . , c(n+L), where L is small compared to the code length and approximately equal to number of chips of delay between the earliest and latest multipath signal. The output of each correlator is applied to a respective first sum-and-dump bank **404**. The magnitudes of the output values of the L sum-and-dumps are calculated in the calculator **406** and then summed in summer **408** to give an output value proportional to the signal energy in the early multipath signals. Similarly, a second correlation bank adaptive matched filter **403** operates on the late samples, using code phases c(n−1), c(n−2), . . . , c(n−L), and each output signal is applied to a respective sum-and-dump circuit in an integrator **405**. The magnitudes of the L sum-and-dump output signals are calculated in calculator **407** and then summed in summer **409** to give a value for the late multipath signal energy. Finally, the subtractor **410** calculates the difference and produces error signal $\epsilon(t)$ of the early and late signal energy values.

The tracking circuit adjusts by means of error signal $\epsilon(\tau)$ the locally generated code phases c(t) to cause the difference between the early and late values to tend toward 0.

Centroid Tracking Method

The optimal spreading code tracking circuit of one embodiment of the present invention is called the squared weighted tracking (or centroid) circuit. Defining τ to denote the time estimate that the tracking circuit calculates, based on some characteristic of f(t), the centroid tracking circuit minimizes the squared weighted error defined as

$$\epsilon = \int_{-\infty}^{\infty} |t - \tau|^2 f(t)dt \tag{19}$$

This function inside the integral has a quadratic form, which has a unique minimum. The value of τ that minimizes ϵ can be found by taking the derivative of the above equation with respect to τ and equating to zero, which gives

$$\int_{-\infty}^{\infty} (-2t + 2\tau)f(t)dt = 0 \tag{20}$$

Therefore, the value of τ that satisfies equation (21)

$$\tau - \frac{1}{\beta} \int_{-\infty}^{\infty} tf(t)dt = 0 \tag{21}$$

is the timing estimate that the tracking circuit calculates, where β is a constant value.

Based on these observations, a realization of an exemplary tracking circuit which minimizes the squared weighted error is shown in FIG. 5*a*. The following equation determines the error signal $\epsilon(\tau)$ of the centroid tracking circuit:

$$\epsilon(\tau) = \sum_{n=1}^{2L} n[|f(\tau - nT/2)| - |f(\tau + nT/2)|] = 0 \tag{22}$$

The value that satisfies $\epsilon(\tau)=0$ is the perfect estimate of the timing.

The early and late multipath signal energy on each side of the centroid point are equal. The centroid tracking circuit shown in FIG. 5*a* consists of an A/D converter **501** which samples an input signal x(t) to form the half-chip offset samples. The half chip offset samples are alternatively grouped as an early set of samples $x(nT+\tau)$ and a late set of samples $x(nT+(T/2)+\tau)$. The first correlation bank adaptive matched filter **502** multiplies each early sample and each late sample by the positive spreading code phases c(n+1), c(n+2), . . . , c(n+L), where L is small compared to the code length and approximately equal to number of chips of delay between the earliest and latest multipath signal. The output signal of each correlator is applied to a respective one of L sum-and-dump circuits of the first sum and dump bank **504**. The magnitude value of each sum-and-dump circuit of the sum and dump bank **504** is calculated by the respective calculator in the calculator bank **506** and applied to a corresponding weighting amplifier of the first weighting bank **508**. The output signal of each weighting amplifier represents the weighted signal energy in a multipath component signal.

The weighted early multipath signal energy values are summed in sample adder **510** to give an output value proportional to the signal energy in the group of multipath signals corresponding to positive code phases which are the early multipath signals. Similarly, a second correlation bank adaptive matched filter **503** operates on the early and late samples, using the negative spreading code phases c(n−1), c(n−2), . . . , c(n−L); each output signal is provided to a respective sum-and-dump circuit of discrete integrator **505**. The magnitude value of the L sum-and-dump output signals are calculated by the respective calculator of calculator bank **507** and then weighted in weighting bank **509**. The weighted late multipath signal energy values are summed in sample adder **511** to give an energy value for the group of multipath signals corresponding to the negative code phases which are the late multipath signals. Finally, the adder **512** calculates the difference of the early and late signal energy values to produce error sample value $\epsilon\tau$).

The tracking circuit of FIG. 5*a* produces error signal $\epsilon(\tau)$ which is used to adjust the locally generated code phase c(nT) to keep the weighted average energy in the early and late multipath signal groups equal. The embodiment shown uses weighting values that increase as the distance from the centroid increases. The signal energy in the earliest and latest multipath signals is probably less than the multipath

signal values near the centroid. Consequently, the difference calculated by the adder **510** is more sensitive to variations in delay of the earliest and latest multipath signals.

Quadratic Detector for Tracking

In the new embodiment of the tracking method, the tracking circuit adjusts sampling phase to be "optimal" and robust to multipath. Let f(t) represent the received signal waveform as in equation 12 above. The particular method of optimizing starts with a delay locked loop with an error signal $\epsilon(\tau)$ that drives the loop. The function $\epsilon(\tau)$ must have only one zero at $\tau=\tau_0$ where τ_0 is optimal. The optimal form for $\epsilon(\tau)$ has the canonical form:

$$\epsilon(\tau)=\int_{-\infty}^{\infty} w(t,\tau)|f(t)|^2 dt \tag{23}$$

where w(t, τ) is a weighting function relating f(t) to the error $\epsilon(\tau)$, and the relationship indicated by equation (24) also holds

$$\epsilon(\tau+\tau_0)=\int_{-\infty}^{\infty} w(t,\tau+\tau_0)|f(t)|^2 dt \tag{24}$$

It follows from equation (24) that w(t, τ) is equivalent to w(t−τ). Considering the slope M of the error signal in the neighborhood of a lock point τ_0:

$$M=\frac{d\epsilon(\tau)}{d\tau}\Big|_{\tau_0}=-\int_{-\infty}^{\infty} w'(t-\tau_0)g(t)dt \tag{25}$$

where w'(t, τ) is the derivative of w(t, τ) with respect to τ, and g(t) is the average of $|f(t)|^2$.

The error $\epsilon(\tau)$ has a deterministic part and a noise part. Let z denote the noise component in $\epsilon(\tau)$, then $|z|^2$ is the average noise power in the error function $\epsilon(\tau)$. Consequently, the optimal tracking circuit maximizes the ratio

$$F=\frac{M^2}{|z|^2} \tag{26}$$

The implementation of the Quadratic Detector is now described. The discrete error value e of an error signal $\epsilon(\tau)$ is generated by performing the operation

$$e=y^T By \tag{27}$$

where the vector y represents the received signal components yi, i=0, 1, . . . L−1, as shown in FIG. 5*b*. The matrix B is an L by L matrix and the elements are determined by calculating values such that the ratio F of equation (26) is maximized.

The Quadratic Detector described above may be used to implement the centroid tracking system described above with reference to FIG. 5*a*. For this implementation, the vector y is the output signal of the sum and dump circuits **504**:

$$y=\{f(\tau-LT), f(\tau-LT+T/2), f(\tau-(L-1)T), \ldots f(\tau), f(\tau+T/2), f(\tau+T), \ldots f(\tau+LT)\}$$

and the matrix B is set forth in table 9.

TABLE 9

B matrix for quadratic form of Centroid Tracking System

L	0	0	0	0	0	0	0	0	0	0
0	L − ½	0	0	0	0	0	0	0	0	0
0	0	L − 1	0	0	0	0	0	0	0	0
.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.
0	0	0	0	½	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	−½	0	0	0	0
.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.
0	0	0	0	0	0	0	0	−L + 1	0	0
0	0	0	0	0	0	0	0	0	−L + ½	0
0	0	0	0	0	0	0	0	0	0	−L

Determining the Minimum Value of L needed:

The value of L in the previous section determines the minimum number of correlators and sum-and-dump elements. L is chosen as small as possible without compromising the functionality of the tracking circuit.

The multipath characteristic of the channel is such that the received chip waveform f(t) is spread over QT_c seconds, or the multipath components occupy a time period of Q chips duration. The value of L chosen is L=Q. Q is found by measuring the particular RF channel transmission characteristics to determine the earliest and latest multipath component signal propagation delay. QT_c is the difference between the earliest and latest multipath component arrival time at a receiver.

Adaptive Vector Correlator

An embodiment of the present invention uses an adaptive vector correlator (AVC) to estimate the channel impulse response and to obtain a reference value for coherent combining of received multipath signal components. The described embodiment employs an array of correlators to estimate the complex channel response affecting each multipath component. The receiver compensates for the channel response and coherently combines the received multipath signal components. This approach is referred to as maximal ratio combining.

Referring to FIG. 6, the input signal x(t) to the system includes interference noise of other message channels, multipath signals of the message channels, thermal noise, and multipath signals of the pilot signal. The signal is provided to AVC **601** which, in the exemplary embodiment, includes a despreading means **602**, channel estimation means for estimating the channel response **604**, correction means for correcting a signal for effects of the channel response **603**, and adder **605**. The AVC despreading means **602** is composed of multiple code correlators, with each correlator using a different phase of the pilot code c(t) provided by the pilot code generator **608**. The output signal of this despreading means corresponds to a noise power level if the local pilot code of the despreading means is not in phase with the input code signal. Alternatively, it corresponds to a received pilot signal power level plus noise power level if the phases of the input pilot code and locally generated pilot code are the same. The output signals of the correlators of the despreading means are corrected for the channel response by the correction means **603** and are applied to the adder **605** which collects all multipath pilot signal power. The channel response estimation means **604** receives the combined pilot

signal and the output signals of the despreading means 602, and provides a channel response estimate signal, w(t), to the correction means 603 of the AVC, and the estimate signal w(t) is also available to the adaptive matched filter (AMF) described below. The output signal of the despreading means 602 is also provided to the acquisition decision means 606 which decides, based on a particular algorithm such as a sequential probability ratio test (SPRT), if the present output levels of the despreading circuits correspond to synchronization of the locally generated code to the desired input code phase. If the detector finds no synchronization, then the acquisition decision means sends a control signal a(t) to the local pilot code generator 608 to offset its phase by one or more chip period. When synchronization is found, the acquisition decision means informs tracking circuit 607, which achieves and maintains a close synchronization between the received and locally generated code sequences.

An exemplary implementation of the Pilot AVC used to despread the pilot spreading code is shown in FIG. 7. The described embodiment assumes that the input signal x(t) has been sampled with sampling period T to form samples x(nT+τ), and is composed of interference noise of other message channels, multipath signals of message channels, thermal noise, and multipath signals of the pilot code. The signal x(nT+τ) is applied to L correlators, where L is the number of code phases over which the uncertainty within the multipath signals exists. Each correlator 701, 702, 703 comprises a multiplier 704, 705, 706, which multiples the input signal with a particular phase of the Pilot spreading code signal c((n+i)T), and sum-and-dump circuits 708, 709, 710. The output signal of each multiplier 704, 705, 706 is applied to a respective sum-and dump circuit 708, 709, 710 to perform discrete integration. Before summing the signal energy contained in the to outputs of the correlators, the AVC compensates for the channel response and the carrier phase rotation of the different multipath signals. Each output of each sum-and-dump 708, 709, 710 is multiplied with a derotation phaser [complex conjugate of ep(nT)] from digital phase lock loop (DPLL) 721 by the respective multiplier 714, 715, 716 to account for the phase and frequency offset of the carrier signal. The Pilot Rake AMF calculates the weighting factors wk, k=1, . . . , L, for each multipath signal by passing the output of each multiplier 714, 715, 716 through a low pass filter (LPF) 711, 712, 713. Each despread multipath signal is multiplied by its corresponding weighting factor in a respective multiplier 717, 718, 719. The output signals of the multipliers 717, 718, 719 are summed in a master adder 720, and the output signal p(nT) of the accumulator 720 consists of the combined despread multipath pilot signals in noise. The output signal p(nT) is also input to the DPLL 721 to produce the error signal ep(nT) for tracking of the carrier phase.

FIGS. 8*a* and 8*b* show alternate embodiments of the AVC which can be used for detection and multipath signal component combining. The message signal AVCs of FIGS. 8*a* and 8*b* use the weighting factors produced by the Pilot AVC to correct the message data multipath signals. The spreading code signal, c(nT) is the spreading code spreading sequence used by a particular message channel and is synchronous with the pilot spreading code signal. The value L is the number of correlators in the AVC circuit.

The circuit of FIG. 8*a* calculates the decision variable Z which is given by

$$Z = w_1 \sum_{i=1}^{N} x(iT+\tau)c(iT) + w_2 \sum_{i=1}^{N} x(iT+\tau)c((i+1)T) + \ldots + w_L \sum_{i=1}^{L} x(iT+\tau) + c((i+L)T) \tag{28}$$

where N is the number of chips in the correlation window. Equivalently, the decision statistic is given by

$$Z = x(T+\tau) \sum_{i=1}^{L} w_i c(iT) + x(2T+\tau) \sum_{i=1}^{L} w_i c((i+1)T) + \ldots + x(NT+\tau) \sum_{i=1}^{L} w_N c((i+N)T) = \sum_{k=1}^{N} x(kT-\tau) \sum_{i=1}^{L} w_i c((i+k-1)T) \tag{29}$$

The alternative implementation that results from equation (29) is shown in FIG. 8*b*.

Referring to FIG. 8*a*, the input signal x(t) is sampled to form x(nT+τ), and is composed of interference noise of other message channels, multipath signals of message channels, thermal noise, and multipath signals of the pilot code. The signal x(nT+τ) is applied to L correlators, where L is the number of code phases over which the uncertainty within the multipath signals exists. Each correlator 801, 802, 803 comprises a multiplier 804, 805, 806, which multiples the input signal by a particular phase of the message channel spreading code signal, and a respective sum-and-dump circuit 808, 809, 810. The output signal of each multiplier 804, 805, 806 is applied to a respective sum-and dump circuit 808, 809, 810 which performs discrete integration. Before summing the signal energy contained in the output signals of the correlators, the AVC compensates for the different multipath signals. Each despread multipath signal and its corresponding weighting factor, which is obtained from the corresponding multipath weighting factor of the pilot AVC, are multiplied in a respective multiplier 817, 818, 819. The output signals of multipliers 817, 818, 819 are summed in a master adder 820, and the output signal z(nT of the accumulator 820 consists of sampled levels of a despread message signal in noise.

The alternative embodiment of the invention includes a new implementation of the AVC despreading circuit for the message channels which performs the sum-and-dump for each multipath signal component simultaneously. The advantage of this circuit is that only one sum-and dump circuit and one adder is necessary. Referring to FIG. 8*b*, the message code sequence generator 830 provides a message code sequence to shift register 831 of length L. The output signal of each register 832, 833, 834, 835 of the shift register 831 corresponds to the message code sequence shifted in phase by one chip. The output value of each register 832, 833, 834, 835 is multiplied in multipliers 836, 837, 838, 839 with the corresponding weighting factor w_k, k=1, . . . , L obtained from the Pilot AVC. The output signals of the L multipliers 836, 837, 838, 839 are summed by the adding circuit 840. The adding circuit output signal and the receiver input signal x(nT +τ) are then multiplied in the multiplier 841 and integrated by the sum-and-dump circuit 842 to produce message signal z(nT).

A third embodiment of the adaptive vector correlator is shown in FIG. 8*c*. The embodiment shown uses the least mean square (LMS) statistic to implement the vector correlator and determines the derotation factors for each multipath component from the received multipath signal. The AVC of FIG. 8*c* is similar to the exemplary implementation of the Pilot AVC used to despread the pilot spreading code shown in FIG. 7. The digital phase locked loop 721 is

replaced by the phase locked loop 850 having voltage controlled oscillator 851, loop filter 852, limiter 853, and imaginary component separator 854. The difference between the corrected despread output signal dos and an ideal despread output signal is provided by adder 855, and the difference signal is a despread error value ide which is further used by the derotation circuits to compensate for errors in the derotation factors.

In a multipath signal environment, the signal energy of a transmitted symbol is spread out over the multipath signal components. The advantage of multipath signal addition is that a substantial portion of signal energy is recovered in an output signal from the AVC. Consequently, a detection circuit has an input signal from the AVC with a higher signal-to-noise ratio (SNR), and so can detect the presence of a symbol with a lower bit-error ratio (BER). In addition, measuring the output of the AVC is a good indication of the transmit power of the transmitter, and a good measure of the system's interference noise.

Adaptive Matched Filter

One embodiment of the current invention includes an Adaptive Matched Filter (AMF) to optimally combine the multipath signal components in a received spread spectrum message signal. The AMF is a tapped delay line which holds shifted values of the sampled message signal and combines these after correcting for the channel response. The correction for the channel response is done using the channel response estimate calculated in the AVC which operates on the Pilot sequence signal. The output signal of the AMF is the combination of the multipath components which are summed to give a maximum value. This combination corrects for the distortion of multipath signal reception. The various message despreading circuits operate on this combined multipath component signal from the AMF.

FIG. 8*d* shows an exemplary embodiment of the AMF. The sampled signal from the A/D converter 870 is applied to the L-stage delay line 872. Each stage of this delay line 872 holds the signal corresponding to a different multipath signal component. Correction for the channel response is applied to each delayed signal component by multiplying the component in the respective multiplier of multiplier bank 874 with the respective weighting factor $w_1, w_2, \ldots, W_L$ from the AVC corresponding to the delayed signal component. All weighted signal components are summed in the adder 876 to give the combined multipath component signal y(t).

The combined multipath component signal y(t) does not include the correction due to phase and frequency offset of the carrier signal. The correction for the phase and frequency offset of the carrier signal is made to y(t) by multiplying y(t) with carrier phase and frequency correction (derotation phasor) in multiplier 878. The phase and frequency correction is produced by the AVC as described previously. FIG. 8*d* shows the correction as being applied before the despreading circuits 880, but alternate embodiments of the invention can apply the correction after the despreading circuits.

Method to Reduce Re-Acquisition Time with Virtual Location

One consequence of determining the difference in code phase between the locally generated pilot code sequence and a received spreading code sequence is that an approximate value for the distance between the base station and a subscriber unit can be calculated. If the SU has a relatively fixed position with respect to the RCS of the base station, the

uncertainty of received spreading code phase is reduced for subsequent attempts at re-acquisition by the SU or RCS. The time required for the base station to acquire the access signal of a SU that has gone "off-hook" contributes to the delay between the SU going off-hook and the receipt of a dial tone from the PSTN. For systems that require a short delay, such as 150 msec for dial tone after off-hook is detected, a method which reduces the acquisition and bearer channel establishment time is desirable. One embodiment of the present invention uses such a method of reducing re-acquisition by use of virtual locating. Additional details of this technique are described in U.S. patent application entitled "VIRTUAL LOCATING OF A FIXED SUBSCRIBER UNIT TO REDUCE RE-ACQUISITION TIME" filed on even date herewith and incorporated herein by reference.

The RCS acquires the SU CDMA signal by searching only those received code phases corresponding to the largest propagation delay of the particular system. In other words, the RCS assumes that all SUs are at a predetermined, fixed distance from the RCS. The first time the SU establishes a channel with the RCS, the normal search pattern is performed by the RCS to acquire the access channel. The normal method starts by searching the code phases corresponding to the longest possible delay, and gradually adjusts the search to the code phases with the shortest possible delay. However, after the initial acquisition, the SU can calculate the delay between the RCS and the SU by measuring the time difference between sending a short access message to the RCS and receiving an acknowledgment message, and using the received Global Pilot channel as a timing reference. The SU can also receive the delay value by having the RCS calculate the round trip delay difference from the code phase difference between the Global Pilot code generated at the RCS and the received assigned pilot sequence from the SU, and then sending the SU the value on a predetermined control channel. Once the round trip delay is known to the SU, the SU may adjust the code phase of the locally generated assigned pilot and spreading code sequences by adding the delay required to make the SU appear to the RCS to be at the predetermined fixed distance from the RCS. Although the method is explained for the largest delay, a delay corresponding to any predetermined location in the system can be used.

A second advantage of the method of reducing re-acquisition by virtual locating is that a conservation in SU power use can be achieved. Note that a SU that is "powered down" or in a sleep mode needs to start the bearer channel acquisition process with a low transmit power level and ramp-up power until the RCS can receive its signal in order to minimize interference with other users. Since the subsequent re-acquisition time is shorter, and because the SU's location is relatively fixed in relation to the RCS, the SU can ramp-up transmit power more quickly because the SU will wait a shorter period of time before increasing transmit power. The SU waits a shorter period because it knows, within a small error range, when it should receive a response from the RCS if the RCS has acquired the SU signal.

The Spread Spectrum Communication System

The Radio Carrier Station (RCS)

The Radio Carrier Station (RCS) of the present invention acts as a central interface between the SU and the remote processing control network element, such as a Radio Distribution Unit (RDU). The interface to the RDU of the present embodiment follows the G.704 standard and an interface according to a modified version of DECT V5.1, but

the present invention can support any interface that can exchange call control and traffic channels. The RCS receives information channels from the RDU including call control data, and traffic channel data such as, but not limited to, 32 kb/s ADPCM, 64 kb/s PCM, and ISDN, as well as system configuration and maintenance data. The RCS also terminates the CDMA radio interface bearer channels with SUs, which channels include both control data, and traffic channel data. In response to the call control data from either the RDU or a SU, the RCS allocates traffic channels to bearer channels on the RF communication link and establishes a communication connection between the SU and the telephone network through an RDU.

As shown in FIG. 9, the RCS receives call control and message information data into the MUXs 905, 906 and 907 through interface lines 901, 902 and 903. Although E1 format is shown, other similar telecommunication formats can be supported in the same manner as described below. The MUXs shown in FIG. 9 may be implemented using circuits similar to that shown in FIG. 10. The MUX shown in FIG. 10 includes system clock signal generator 1001 consisting of phase locked oscillators (not shown) which generate clock signals for the Line PCM highway 1002 (which is part of PCM Highway 910), and high speed bus (HSB) 970; and the MUX Controller 1010 which synchronizes the system clock 1001 to interface line 1004. It is contemplated that the phase lock oscillators can provide timing signals for the RCS in the absence of synchronization to a line. The MUX Line Interface 1011 separates the call control data from the message information data. Referring to FIG. 9, each MUX provides a connection to the Wireless Access Controller (WAC) 920 through the PCM highway 910. The MUX controller 1010 also monitors the presence of different tones present in the information signal by means of tone detector 1030.

Additionally, the MUX Controller 1010 provides the ISDN D channel network signaling locally to the RDU. The MUX line interface 1011, such as a FALC 54, includes an El interface 1012 which consists of a transmit connection pair (not shown) and a receive connection pair (not shown) of the MUX connected to the RDU or Central Office (CO) ISDN Switch at the data rate of 2.048 Mbps. The transmit and receive connection pairs are connected to the E1 interface 1012 which translates differential tri-level transmit/receive encoded pairs into levels for use by the Framer 1015. The line interface 1011 uses internal phase-locked-loops (not shown) to produce E1-derived 2.048 MHz, and 4.096 MHz clocks as well as an 8 KHz frame-sync pulse. The line interface can operate in clock-master or clock-slave mode. While the exemplary embodiment is shown as using an E1 Interface, it is contemplated that other types of telephone lines which convey multiple calls may be used, for example, T1 lines or lines which interface to a Private Branch Exchange (PBX).

The line interface framer 1015 frames the data streams by recognizing the framing patterns on channel-1 (time-slot 0) of the incoming line, and inserts and extracts service bits, generates/checks line service quality information.

As long as a valid E1 signal appears at the E1 Interface 1012, the FALC 54, recovers a 2.048 MHz PCM clock signal from the E1 line. This clock, via System Clock 1001, is used system wide as a PCM Highway Clock signal. If the E1 Line fails, the FALC 54 continues to deliver a PCM Clock derived from an oscillator signal o(t) connected to the sync input (not shown) of the FALC 54. This PCM Clock serves the RCS system until another MUX with an operational E1 line assumes responsibility for generating the system clock signals.

The framer 1015 generates a Received Frame Sync Pulse, which in turn can be used to trigger the PCM Interface 1016 to transfer data onto the line PCM Highway 1002 and into the RCS System for use by other elements. Since all E1 lines are frame synchronized, all Line PCM Highways are also frame synchronized. From this 8 kHz PCM Sync pulse, the system clock signal generator 1001 of the MUX uses a Phase Locked Loop (not shown) to synthesize the PN×2 clock [e.g., 15.96 MHz)($W_0(t)$]. The frequency of this clock signal is different for different transmission bandwidths, as described in Table 7.

The MUX includes a MUX Controller 1010, such as a 25 MHz Quad Integrated Communications Controller, containing a microprocessor 1020, program memory 1021, and Time Division Multiplexer (TDM) 1022. The TDM 1022 is coupled to receive the signal provided by the Framer 1015, and extracts information placed in time slots 0 and 16. The extracted information governs how the MUX controller 1010 processes the Link Access Protocol-D (LAPD) data link. The call control and bearer modification messages, such as those defined as V5.1 Network layer messages, are either passed to the WAC, or used locally by the MUX controller 1010.

The RCS Line PCM Highway 1002 is connected to and originates with the Framer 1015 through PCM Interface 1016, and comprises of a 2.048 MHz stream of data in both the transmit and receive direction. The RCS also contains a High Speed Bus (HSB) 970 which is the communication link between the MUX, WAC, to and MIUs. The HSB 970 supports a data rate of, for example, 100 Mbit/sec. Each of the MUX, WAC, and MIU access the HSB using arbitration. The RCS of the present invention also can include several MUXs requiring one board to be a "master" and the rest "slaves". Details on the implementation of the HSB may be found in a U.S. patent application entitled PARALLEL PACKETIZED INTERMODULE ARBITRATED HIGH SPEED CONTROL AND DATA BUS, filed on even date herewith, which is hereby incorporated by reference.

Referring to FIG. 9, the Wireless Access Controller (WAC) 920 is the RCS system controller which manages call control functions and interconnection of data streams between the MUXs 905, 906, 907, Modem Interface Units (MIUs) 931, 932, 933. The WAC 920 also controls and monitors other RCS elements such as the VDC 940, RF 950, and Power Amplifiers 960. The WAC 920 as shown in FIG. 11, allocates bearer channels to the modems on each MIU 931, 932, 933 and allocates the message data on line PCM Highway 910 from the MUXs 905, 906, 907 to the modems on the MIUs 931, 932, 933. This allocation is made through the System PCM Highway 911 by means of a time slot interchange on the WAC 920. If more than one WAC is present for redundancy purposes, the WACs determines the Master-Slave relationship with a second WAC. The WAC 920 also generates messages and paging information responsive to call control signals from the MUXs 905, 906, 907 received from a remote processor, such as an RDU; generates Broadcast Data which is transmitted to the MIU master modem 934; and controls the generation by the MIU MM 934 of the Global system Pilot spreading code sequence. The WAC 920 also is connected to an external Network Manager (NM) 980 for craftperson or user access.

Referring to FIG. 11, the WAC includes a time-slot interchanger (TSI) 1101 which transfers information from one time slot in a Line PCM Highway or System PCM Highway to another time slot in either the same or different Line PCM Highway or System PCM Highway. The TSI 1101 is connected to the WAC controller 1111 of FIG. 11

which controls the assignment or transfer of information from one time slot to another time slot and stores this information in memory 1120. The exemplary embodiment of the invention has four PCM Highways 1102, 1103, 1104, 1105 connected to the TSI. The WAC also is connected to the HSB 970, through which WAC communicates to a second WAC (not shown), to the MUXs and to the MIUs.

Referring to FIG. 11, the WAC 920 includes a WAC controller 1111 employing, for example, a microprocessor 1112, such as a Motorola MC68040 and a communications processor 1113, such as the Motorola MC68360 QUICC communications processor, and a clock oscillator 1114 which receives a clock synch signal wo(t) from the system clock generator. The clock generator is located on a MUX (not shown) to provide timing to the WAC controller 1111. The WAC controller 1111 also includes memory 1120 including Flash Prom 1121 and SRAM memory 1122. The Flash Prom 1121 contains the program code for the WAC controller 1111, and is reprogrammable for new software programs downloaded from an external source. The SRAM 1122 is provided to contain the temporary data written to and read from memory 1120 by the WAC controller 1111.

A low speed bus 912 is connected to the WAC 920 for transferring control and status signals between the RF Transmitter/Receiver 950, VDC 940, RF 950 and Power Amplifier 960 as shown in FIG. 9. The control signals are sent from the WAC 920 to enable or disable the RF Transmitters/Receiver 950 or Power amplifier 960, and the status signals are sent from the RF Transmitters/Receiver 950 or Power amplifier 960 to monitor the presence of a fault condition.

Referring to FIG. 9, the exemplary RCS contains at least one MIU 931, which is shown in FIG. 12 and now described in detail. The MIU of the exemplary embodiment includes six CDMA modems, but the invention is not limited to this number of modems. The MIU includes a System PCM Highway 1201 connected to each of the CDMA Modems 1210, 1211, 1212, 1215 through a PCM Interface 1220, a Control Channel Bus 1221 connected to MIU controller 1230 and each of the CDMA Modems 1210, 1211, 1212, 1213, an MIU clock signal generator (CLK) 1231, and a modem output combiner 1232. The MIU provides the RCS with the following functions: the MIU controller receives CDMA Channel Assignment Instructions from the WAC and assigns a modem to a user information signal which is applied to the line interface of the MUX and a modem to receive the CDMA channel from the SU; it also combines the CDMA Transmit Modem Data for each of the MIU CDMA modems; multiplexes I and Q transmit message data from the CDMA modems for transmission to the VDC; receives Analog I and Q receive message data from the VDC; distributes the I and Q data to the CDMA modems; transmits and receives digital AGC Data; distributes the AGC data to the CDMA modems; and sends MIU Board Status and Maintenance Information to the WAC 920.

The MIU controller 1230 of the exemplary embodiment of the present invention contains one communication microprocessor 1240, such as the MC68360 "QUICC" Processor, and includes a memory 1242 having a Flash Prom memory 1243 and a SRAM memory 1244. Flash Prom 1243 is provided to contain the program code for the Microprocessors 1240, and the memory 1243 is downloadable and reprogrammable to support new program versions. SRAM 1244 is provided to contain the temporary data space needed by the MC68360 Microprocessor 1240 when the MIU controller 1230 reads or writes data to memory The MIU CLK circuit 1231 provides a timing signal to the MIU controller 1230, and also provides a timing signal to the CDMA modems. The MIU CLK circuit 1231 receives and is synchronized to the system clock signal wo(t). The controller clock signal generator 1213 also receives and synchronizes to the spreading code clock signal pn(t) which is distributed to the CDMA modems 1210, 1211, 1212, 1215 from the MUX.

The RCS of the present embodiment includes a System Modem 1210 contained on one MIU. The System Modem 1210 includes a Broadcast spreader (not shown) and a Pilot Generator (not shown). The Broadcast Modem provides the broadcast information used by the exemplary system, and the broadcast message data is transferred from the MIU controller 1230 to the System Modem 1210. The System Modem also includes four additional modems (not shown) which are used to transmit the signals CT1 through CT4 and AX1 through AX4. The System Modem 1210 provides unweighted I and Q Broadcast message data signals which are applied to the VDC. The VDC adds the Broadcast message data signal to the MIU CDMA Modem Transmit Data of all CDMA modems 1210, 1211, 1212, 1215, and the Global Pilot signal.

The Pilot Generator (PG) 1250 provides the Global Pilot signal which is used by the present invention, and the Global Pilot signal is provided to the CDMA modems 1210, 1211, 1212, 1215 by the MIU controller 1230. However, other embodiments of the present invention do not require the MIU controller to generate the Global Pilot signal, but include a Global Pilot signal generated by any form of CDMA Code Sequence generator. In the described embodiment of the invention, the unweighted I and Q Global Pilot signal is also sent to the VDC where it is assigned a weight, and added to the MIU CDMA Modem transmit data and Broadcast message data signal.

System timing in the RCS is derived from the E1 interface. There are four MUXs in an RCS, three of which (905, 906 and 907) are shown in FIG. 9. Two MUXs are located on each chassis. One of the two MUXs on each chassis is designated as the master, and one of the masters is designated as the system master. The MUX which is the system master derives a 2.048 Mhz PCM clock signal from the E1 interface using a phase locked loop (not shown). In turn, the system master MUX divides the 2.048 Mhz PCM clock signal in frequency by 16 to derive a 128 KHz reference clock signal. The 128 KHz reference clock signal is distributed from the MUX that is the system master to all the other MUXs. In turn, each MUX multiplies the 128 KHz reference clock signal in frequency to synthesize the system clock signal which has a frequency that is twice the frequency of the PN-clock signal. The MUX also divides the 128 KHz clock signal in frequency by 16 to generate the 8 KHz frame synch signal which is distributed to the MIUs. The system clock signal for the exemplary embodiment has a frequency of 11.648 Mhz for a 7 MHz bandwidth CDMA channel Each MUX also divides the system clock signal in frequency by 2 to obtain the PN-clock signal and further divides the PN-clock signal in frequency by 29 877 120 (the PN sequence length) to generate the PN-synch signal which indicates the epoch boundaries. The PN-synch signal from the system master MUX is also distributed to all MUXs to maintain phase alignment of the internally generated clock signals for each MUX. The PN-synch signal and the frame synch signal are aligned. The two MUXs that are designated as the master MUXs for each chasis then distribute both the system clock signal and the PN-clock signal to the MIUs and the VDC.

The PCM Highway Interface 1220 connects the System PCM Highway 911 to each CDMA Modem 1210, 1211,

1212, 1215. The WAC controller transmits Modem Control information, including traffic message control signals for each respective user information signal, to the MIU controller 1230 through the HSB 970. Each CDMA Modem 1210, 1211, 1212, 1215 receives a traffic message control signal, which includes signaling information, from the MIU controller 1111. Traffic message control signals also include call control (CC) information and spreading code and despreading code sequence information.

The MIU also includes the Transmit Data Combiner 1232 which adds weighted CDMA modem transmit data including In-phase (I) and Quadrature (Q) modem transmit data from the CDMA modems 1210, 1211, 1212, 1215 on the MIU. The I modem transmit data is added separately from the Q modem transmit data. The combined I and Q modem transmit data output signal of the Transmit Data Combiner 1232 is applied to the I and Q multiplexer 1233 that creates a single CDMA transmit message channel composed of the I and Q modem transmit data multiplexed into a digital data stream.

The Receiver Data Input Circuit (RDI) 1234 receives the Analog Differential I and Q Data from the Video Distribution Circuit (VDC) 940 shown in FIG. 9 and distributes Analog Differential I and Q Data to each of the CDMA Modems 1210, 1211, 1212, 1215 of the MIU. The Automatic Gain Control Distribution Circuit (AGC) 1235 receives the AGC Data signal from the VDC and distributes the AGC Data to each of the CDMA Modems of the MIU. The TRL circuit 1233 receives the Traffic lights information and similarly distributes the Traffic light data to each of the Modems 1210, 1211, 1212, 1215.

The CDMA Modem

The CDMA modem provides for generation of CDMA spreading code sequences and synchronization between transmitter and receiver. It also provides four full duplex channels (TR0, TR1, TR2, TR3) programmable to 64, 32, 16, and 8 ksym/sec. each, for spreading and transmission at a specific power level. The CDMA mode measures the received signal strength to allow Automatic Power Control, it generates and transmits pilot signals, and encodes and decodes using the signal for forward error correction (FEC). The modem in an SU also performs transmitter spreading code pulse shaping using an FIR filter. The CDMA modem is also used by the Subscriber Unit (SU), and in the following discussion those features which are used only by the SU are distinctly pointed out. The operating frequencies of the CDMA modem are given in Table 10.

TABLE 10

Operating Frequencies			
Bandwidth (MHz)	Chip Rate (MHz)	Symbol Rate (KHz)	Gain (Chips/Symbol)
7	5.824	64	91
10	8.320	64	130
10.5	8.512	64	133
14	11.648	64	182
15	12.480	64	195

Each CDMA modem 1210, 1211, 1212, 1215 of FIG. 12, and as shown in FIG. 13, is composed of a transmit section 1301 and a receive section 1302. Also included in the CDMA modem is a control center 1303 which receives control messages CNTRL from the external system. These messages are used, for example, to assign particular spreading codes, activate the spreading or despreading, or to assign transmission rates. In addition, the CDMA modem has a code generator means 1304 used to generate the various spreading and despreading codes used by the CDMA modem. The transmit section 1301 is for transmitting the input information and control signals $m_i(t)$, $i=1,2, \ldots I$ as spread-spectrum processed user information signals $sc_j(t)$, $j=1,2, \ldots J$. The transmit section 1301 receives the global pilot code from the code generator 1304 which is controlled by the control means 1303. The spread spectrum processed user information signals are ultimately added to other similar processed signals and transmitted as CDMA channels over the CDMA RF forward message link, for example to the SUs. The receive section 1302 receives CDMA channels as r(t) and despreads and recovers the user information and control signals $rc_k(t)$, $k=1,2, \ldots K$ transmitted over the CDMA RF reverse message link, for example to the RCS from the SUs.

CDMA Modem Transmitter Section

Referring to FIG. 14, the code generator means 1304 includes Transmit Timing Control Logic 1401 and spreading code PN-Generator 1402, and the Transmit Section 1301 includes Modem Input Signal Receiver (MISR) 1410, Convolution Encoders 1411, 1412, 1413, 1414, Spreaders 1420, 1421, 1422, 1423, 1424, and Combiner 1430. The Transmit Section 1301 receives the message data channels MESSAGE, convolutionally encodes each message data channel in the respective convolutional encoder 1411, 1412, 1413, 1414, modulates the data with random spreading code sequence in the respective spreader 1420, 1421, 1422, 1423, 1424, and combines modulated data from all channels, including the pilot code received in the described embodiment from the code generator, in the combiner 1430 to generate I and Q components for RF transmission. The Transmitter Section 1301 of the present embodiment supports four (TR0, TR1, TR2, TR3) 64, 32, 16, 8 kb/s programmable channels. The message channel data is a time multiplexed signal received from the PCM highway 1201 through PCM interface 1220 and input to the MISR 1410.

FIG. 15 is a block diagram of an exemplary MISR 1410. For the exemplary embodiment of the present invention, a counter is set by the 8 KHz frame synchronization signal MPCMSYNC and is incremented by 2.048 MHz MPCMCLK from the timing circuit 1401. The counter output is compared by comparator 1502 against TRCFG values corresponding to slot time location for TR0, TR1, TR2, TR3 message channel data; and the TRCFG values are received from the MIU Controller 1230 in MCTRL. The comparator sends count signal to the registers 1505, 1506, 1507 and 1508 which clocks message channel data into buffers 1510, 1511, 1512, 1513 using the TXPCNCLK timing signal derived from the system clock. The message data is provided from the signal MSGDAT from the PCM highway signal MESSAGE when enable signals TR0EN, TR1EN, TR2EN and TR3EN from Timing Control Logic 1401 are active. In further embodiments, MESSAGE may also include signals that enable registers depending upon an encryption rate or data rate. If the counter output is equal to one of the channel location addresses, the specified transmit message data in registers 1510, 1511, 1512, 1513 are input to the convolutional encoders 1411, 1412, 1413, 1414 shown in FIG. 14.

The convolutional encoder enables the use of Forward Error Correction (FEC) techniques, which are well known in the art. FEC techniques depend on introducing redundancy in generation of data in encoded form. Encoded data is transmitted and the redundancy in the data enables the

receiver decoder device to detect and correct errors. One embodiment of the present invention employs convolutional encoding. Additional data bits are added to the data in the encoding process and are the coding overhead. The coding rate is expressed as the ratio of data bits transmitted to the total bits (code data+redundant data) transmitted and is called the rate "R" of the code.

Convolution codes are codes where each code bit is generated by the convolution of each new uncoded bit with a number of previously coded bits. The total number of bits used in the encoding process is referred to as the constraint length, "K", of the code. In convolutional coding, data is clocked into a shift register of K bits length so that an incoming bit is clocked into the register, and it and the existing K−1 bits are convolutionally encoded to create a new symbol. The convolution process consists of creating a symbol consisting of a module-2 sum of a certain pattern of available bits, always including the first bit and the last bit in at least one of the symbols.

FIG. 16 shows the block diagram of a K=7, R=½ convolution encoder suitable for use as the encoder 1411 shown in FIG. 14. This circuit encodes the TR0 Channel as used in one embodiment of the present invention. Seven-Bit Register 1601 with stages Q1 through Q7 uses the signal TXPNCLK to clock in TR0 data when the TR0EN signal is asserted. The output value of stages Q1, Q2, Q3, Q4, Q6, and Q7 are each combined using EXCLUSIVE-OR Logic 1602, 1603 to produce respective I and Q channel FEC data for the TR0 channel FECTR0DI and FECTR0DQ.

Two output symbol streams FECTR0DI and FECTR0DQ are generated. The FECTR0DI symbol stream is generated by EXCLUSIVE OR Logic 1602 of shift register outputs corresponding to bits 6, 5, 4,3, and 0, (Octal 171) and is designed as In phase component "I" of the transmit message channel data. The symbol stream FECTR0DQ is likewise generated by EXCLUSIVE-OR logic 1603 of shift register outputs from bits 6, 4 3, 1 and 0, (Octal 133) and is designated as Quadrature component "Q" of the transmit message channel data. Two symbols are transmitted to represent a single encoded bit creating the redundancy necessary to enable error correction to take place on the receiving end.

Referring to FIG. 14, the shift enable clock signal for the transmit message channel data is generated by the Control Timing Logic 1401. The convolutionally encoded transmit message channel output data for each channel is applied to the respective spreader 1420, 1421, 1422, 1423, 1424 which multiplies the transmit message channel data by its preassigned spreading code sequence from code generator 1402. This spreading code sequence is generated by control 1303 as previously described, and is called a random pseudonoise signature sequence (PN-code).

The output signal of each spreader 1420, 1421, 1422, 1423, 1424 is a spread transmit data channel. The operation of the spreader is as follows: the spreading of channel output (I+jQ) multiplied by a random sequence (PNI+jPNQ) yields the In-phase component I of the result being composed of (I xor PNI) and (−Qxor PNQ). Quadrature component Q of the result is (Q xor PNI) and (I xor PNQ). Since there is no channel data input to the pilot channel logic (I=1, Q values are prohibited), the spread output signal for pilot channels yields the respective sequences PNI for I component and PNQ for Q component.

The combiner 1430 receives the I and Q spread transmit data channels and combines the channels into an I modem transmit data signal (TXIDAT) and a Q modem transmit data signal (TXQDAT). The I-spread transmit data and the Q spread transmit data are added separately.

For an SU, the CDMA modem Transmit Section 1301 includes the FIR filters to receive the I and Q channels from the combiner to provide pulse shaping, close-in spectral control and x/sin (x) correction for the transmitted signal. Separate but identical FIR filters receive the I and Q spread transmit data streams at the chipping rate, and the output signal of each of the filters is at twice the chipping rate. The exemplary FIR filters are 28 tap even symmetrical filters, which upsample (interpolate) by 2. The upsampling occurs before the filtering, so that 28 taps refers to 28 taps at twice the chipping rate, and the upsampling is accomplished by setting every other sample a zero. Exemplary coefficients are shown in Table 11.

TABLE 11

Coefficient Values														
Coeff. No.:	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Value:	3	−11	−34	−22	19	17	−32	−19	52	24	−94	−31	277	468
Coeff. No.	14	15	16	17	18	19	20	21	22	24	25	26	27	
Value	277	−31	−94	24	52	−19	−32	17	19	−22	−34	−11	3	

CDMA Modem Receiver Section

Referring to FIGS. 9 and 12, the RF receiver 950 of the present embodiment accepts analog input I and Q CDMA channels, which are transmitted to the CDMA modems 1210, 1211, 1212, 1215 through the MIUs 931, 932, 933 from the VDC 940. These I and Q CMDA channel signals are sampled by the CDMA modem receive section 1302 (shown in FIG. 13) and converted to I and Q digital receive message signal using an Analog to Digital (A/D) converter 1730, shown in FIG. 17. The sampling rate of the A/D converter of the exemplary embodiment of the present invention is equivalent to the despreading code rate. The I and Q digital receive message signals are then despread with correlators using six different complex spreading code sequences corresponding to the despreading code sequences of the four channels (TR0, TR1, TR2, TR3), APC information and the pilot code.

Time synchronization of the receiver to the received signal is separated into two phases; there is an initial acquisition phase and then a tracking phase after the signal timing has been acquired. The initial acquisition is done by shifting the phase of the locally generated pilot code sequence relative to the received signal and comparing the output of the pilot despreader to a threshold. The method used is called sequential search. Two thresholds (match and dismiss) are calculated from the auxiliary despreader. Once the signal is acquired, the search process is stopped and the tracking process begins. The tracking process maintains the code generator 1304 (shown in FIGS. 13 and 17) used by the receiver in synchronization with the incoming signal. The

tracking loop used is the Delay-Locked Loop (DLL) and is implemented in the acquisition & track 1701 and the IPM 1702 blocks of FIG. 17.

In FIG. 13, the modem controller 1303 implements the Phase Lock Loop (PLL) as a software algorithm in SW PLL logic 1724 of FIG. 17 that calculates the phase and frequency shift in the received signal relative to the transmitted signal. The calculated phase shifts are used to derotate the phase shifts in rotate and combine blocks 1718, 1719, 1720, 1721 of the multipath data signals for combining to produce output signals corresponding to receive channels TR0', TR1', TR2', TR3'. The data is then Viterbi decoded in Viterbi Decoders 1713, 1714, 1715, 1716 to remove the convolutional encoding in each of the received message channels.

FIG. 17 indicates that the Code Generator 1304 provides the code sequences $Pn_i(t)$, i=1,2, . . . I used by the receive channel despreaders 1703, 1704, 1705, 1706, 1707, 1708, 1709. The code sequences generated are timed in response to the SYNK signal of the system clock signal and are determined by the CCNTRL signal from the modem controller 1303 shown in FIG. 13. Referring to FIG. 17, the CDMA modem receiver section 1302 includes Adaptive Matched Filter (AMF) 1710, Channel despreaders 1703, 1704, 1705, 1706, 1707, 1708, 1709, Pilot AVC 1711, Auxiliary AVC 1712, Viterbi decoders 1713, 1714, 1715, 1716, Modem output interface (MOI) 1717, Rotate and Combine logic 1718, 1719, 1720, 1721, AMF Weight Generator 1722, and Quantile Estimation logic 1723.

In another embodiment of the invention, the CDMA modem receiver also includes a Bit error Integrator to measure the BER of the channel and idle code insertion logic between the Viterbi decoders 1713, 1714, 1715, 1716 and the MOI 1717 to insert idle codes in the event of loss of the message data.

The Adaptive Matched Filter (AMF) 1710 resolves multipath interference introduced by the air channel. The exemplary AMF 1710 uses an 11 stage complex FIR filter as shown in FIG. 18. The received I and Q digital message signals are received at the register 1820 from the A/D 1730 of FIG. 17 and are multiplied in multipliers 1801, 1802, 1803, 1810, 1811 by I and Q channel weights W1 to W11 received from AMF weight generator 1722 of FIG. 17. In the exemplary embodiment, the A/D 1730 provides the I and Q digital receive message signal data as 2's complement values, 6 bits for I and 6 bits for Q which are clocked through an 11 stage shift register 1820 responsive to the receive spreading-code clock signal RXPNCLK. The signal RXPNCLK is generated by the timing section 1401 of code generation logic 1304. Each stage of the shift register is tapped and complex multiplied in the multipliers 1801, 1802, 1803, 1810, 1811 by individual (6-bit I and 6-bit Q) weight values to provide 11 tap-weighted products which are summed in adder 1830, and limited to 7-bit I and 7-bit Q values.

The CDMA modem receive section 1302 (shown in FIG. 13) provides independent channel despreaders 1703, 1704, 1705, 1706, 1707, 1708, 1709 (shown in FIG. 17) for despreading the message channels. The described embodiment despreads 7 message channels, each despreader accepting a 1-bit I by 1-bit Q despreading code signal to perform a complex correlation of this code against a 8-bit I by 8-bit Q data input. The 7 despreaders correspond to the 7 channels: Traffic Channel 0 (TR0'), TR1', TR2, TR3', AUX (a spare channel), Automatic Power Control (APC) and pilot (PLT).

The Pilot AVC 1711 shown in FIG. 19 receives the I and Q Pilot Spreading code sequence values PCI and PCQ into shift register 1920 responsive to the timing signal RXPNCLK, and includes 11 individual despreaders 1901 through 1911 each correlating the I and Q digital receive message signal data with a one chip delayed version of the same pilot code sequence. Signals OE1, OE2, . . . OE11 are used by the modem control 1303 to enable the despreading operation. The output signals of the despreaders are combined in combiner 1920 forming correlation signal DSPRDAT of the Pilot AVC 1711, which is received by the ACQ & Track logic 1701 (shown in FIG. 17), and ultimately by modem controller 1303 (shown in FIG. 13). The ACQ & Track logic 1701 uses the correlation signal value to determine if the local receiver is synchronized with its remote transmitter.

The Auxiliary AVC 1712 also receives the I and Q digital receive message signal data and, in the described embodiment, includes four separate despreaders 2001, 2002, 2003, 2004 as shown in FIG. 20. Each despreader receives and correlates the I and Q digital receive message data with delayed versions of the same despreading code sequence PARI and PARQ which are provided by code generator 1304 input to and contained in shift register 2020. The output signals of the despreaders 2001, 2002, 2003, 2004 are combined in combiner 2030 which provides noise correlation signal ARDSPRDAT. The auxiliary AVC spreading code sequence does not correspond to any transmit spreading code sequence of the system. Signals OE1, OE2, . . . OE4 are used by the modem control 1303 to enable the despreading operation. The Auxiliary AVC 1712 provides a noise correlation signal ARDSPRDAT from which quantile estimates are calculated by the Quantile estimator 1733, and provides a noise level measurement to the ACQ & Track logic 1701 (shown in FIG. 17) and modem controller 1303 (shown in FIG. 13).

Each despread channel output signal corresponding to the received message channels TR0', TR1', TR2', and TR3' is input to a corresponding Viterbi decoder 1713, 1714, 1715, 1716 shown in FIG. 17 which performs forward error correction on convolutionally encoded data. The Viterbi decoders of the exemplary embodiment have a constraint length of K=7 and a rate of R=½. The decoded despread message channel signals are transferred from the CDMA modem to the PCM Highway 1201 through the MOI 1717. The operation of the MOI is essentially the same as the operation of the MISR of the transmit section 1301 (shown in FIG. 13) except in reverse.

The CDMA modem receiver section 1302 implements several different algorithms during different phases of the acquisition, tracking and despreading of the receive CDMA message signal.

When the received signal is momentarily lost (or severely degraded) the idle code insertion algorithm inserts idle codes in place of the lost or degraded receive message data to prevent the user from hearing loud noise bursts on a voice call. The idle codes are sent to the MOI 1717 (shown in FIG. 17) in place of the decoded message channel output signal from the Viterbi decoders 1713, 1714, 1715, 1716. The idle code used for each traffic channel is programmed by the Modem Controller 1303 by writing the appropriate pattern IDLE to the MOI, which in the present embodiment is a 8 bit word for a 64 kb/s stream, 4 bit word for a 32 kb/s stream.

Modem Algorithms for Acquisition and Tracking of Received Pilot Signal

The acquisition and tracking algorithms are used by the receiver to determine the approximate code phase of a

received signal, synchronize the local modem receiver despreaders to the incoming pilot signal, and track the phase of the locally generated pilot code sequence with the received pilot code sequence. Referring to FIGS. 13 and 17, the algorithms are performed by the Modem controller 1303, which provides clock adjust signals to code generator 1304. These adjust signals cause the code generator for the despreaders to adjust locally generated code sequences in response to measured output values of the Pilot Rake 1711 and Quantile values from quantile estimators 1723B. Quantile values are noise statistics measured from the In-phase and Quadrature channels from the output values of the AUX Vector Correlator 1712 (shown in FIG. 17). Synchronization of the receiver to the received signal is separated into two phases: an initial acquisition phase and a tracking phase. The initial acquisition phase is accomplished by clocking the locally generated pilot spreading code sequence at a higher or lower rate than the received signal's spreading code rate, sliding the locally generated pilot spreading code sequence and performing sequential probability ratio test (SPRT) on the output of the Pilot Vector correlator 1711. The tracking phase maintains the locally generated spreading code pilot sequence in synchronization with the incoming pilot signal. Details of the quantile estimators 1723B may be found in U.S. patent application Ser. No. 08/218,198 entitled "ADAPTIVE POWER CONTROL FOR A SPREAD SPECTRUM COMMUNICATIONS SYSTEM" which is incorporated by reference herein for its teachings on adaptive power control systems.

The SU cold acquisition algorithm is used by the SU CDMA modem when it is first powered up, and therefore has no knowledge of the correct pilot spreading code phase, or when an SU attempts to reacquire synchronization with the incoming pilot signal but has taken an excessive amount of time. The cold acquisition algorithm is divided into two sub-phases. The first subphase consists of a search over the length 233415 code used by the FBCH. Once this sub-code phase is acquired, the pilot's 233415×128 length code is known to within an ambiguity of 128 possible phases. The second subphase is a search of these remaining 128 possible phases. In order not to lose synch with the FBCH, in the second phase of the search, it is desirable to switch back and forth between tracking of the FBCH code and attempting acquisition of the pilot code.

The RCS acquisition of short access pilot (SAXPT) algorithm is used by an RCS CDMA modem to acquire the SAXPT pilot signal of an SU. Additional details of this technique are described in U.S. patent application entitled "A METHOD OF CONTROLLING INITIAL POWER RAMP-UP IN CDMA SYSTEMS BY USING SHORT CODES" filed on even date herewith and herein incorporated by reference. The algorithm is a fast search algorithm because the SAXPT is a short code sequence of length N, where N=chips/symbol, and ranges from 45 to 195, depending on the system's bandwidth. The search cycles through all possible phases until acquisition is complete.

The RCS acquisition of the long access pilot (LAXPT) algorithm begins immediately after acquisition of SAXPT. The SU's code phase is known within a multiple of a symbol duration, so in the exemplary embodiment of the invention there may be 7 to 66 phases to search within the round trip delay from the RCS. This bound is a result of the SU pilot signal being synchronized to the RCS Global pilot signal.

The re-acquisition algorithm begins when loss of code lock (LOL) occurs. A Z-search algorithm is used to speed the process on the assumption that the code phase has not drifted far from where it was the last time the system was locked. The RCS uses a maximum width of the Z-search windows bounded by the maximum round trip propagation delay.

The Pre-Track period immediately follows the acquisition or re-acquisition algorithms and immediately precedes the tracking algorithm. Pre-track is a fixed duration period during which the receive data provided by the modem is not considered valid. The Pre-Track period allows other modem algorithms, such as those used by the ISW PLL 1724, ACQ & Tracking, AMF Weight GEN 1722, to prepare and adapt to the current channel. The Pre-Track period is two parts. The first part is the delay while the code tracking loop pulls in. The second part is the delay while the AMF tap weight calculations are performed by the AMF Weight Gen 1722 to produce settled weighting coefficients. Also in the second part of the Pre-Track period, the carrier tracking loop is allowed to pull in by the SW PLL 1724, and the scalar quantile estimates are performed in the Quantile estimator 1723A.

The Tracking Process is entered after the Pre-Track period ends. This process is actually a repetitive cycle and is the only process phase during which receive data provided by the modem may be considered valid. The following operations are performed during this phase: AMF Tap Weight Update, Carrier Tracking, Code Tracking, Vector Quantile Update, Scalar Quantile Update, Code Lock Check, Derotation and Symbol Summing, and Power Control (forward and reverse)

If LOL is detected, the modem receiver terminates the Track algorithm and automatically enters the reaquisition algorithm. In the SU, a LOL causes the transmitter to be shut down. In the RCS, LOL causes forward power control to be disabled with the transmit power held constant at the level immediately prior to loss of lock. It also causes the return power control information being transmitted to assume a 010101... pattern, causing the SU to hold its transmit power constant. This can be performed using the signal lock check function which generates the reset signal to the acquisition and tracking circuit 1701.

Two sets of quantile statistics are maintained, one by Quantile estimator 1723B and the other by the scalar Quantile Estimator 1723A. Both are used by the modem controller 1303. The first set is the "vector" quantile information, so named because it is calculated from the vector of four complex values generated by the AUX AVC receiver 1712. The second set is the scalar quantile information, which is calculated from the single complex value AUX signal that is output from the AUX Despreader 1707. The two sets of information represent different sets of noise statistics used to maintain a pre-determined Probability of False Alarm (P_{fa}). The vector quantile data is used by the acquisition and reaquisition algorithms implemented by the modem controller 1303 to determine the presence of a received signal in noise, and the scalar quantile information is used by the code lock check algorithm.

For both the vector and scalar cases, quantile information consists of calculated values of lambda0 through lambda2, which are boundary values used to estimate the probability distribution function (p.d.f) of the despread receive signal and determine whether the modem is locked to the PN code. The Aux_Power value used in the following C-subroutine is the magnitude squared of the AUX signal output of the scalar correlator array for the scalar quantiles, and the sum of the magnitudes squared for the vector case. In both cases the quantiles are then calculated using the following C-subroutine:

```
for (n = 0; n < 3; n++) {
   lambda [n] += (lambda [n] < Aux_Power) ? CG[n] : GM[n];
}
```

where CG[n] are positive constants and GM[n] are negative constants (different values are used for scalar and vector quantiles).

During the acquisition phase, the search of the incoming pilot signal with the locally generated pilot code sequence employs a series of sequential tests to determine if the locally generated pilot code has the correct code phase relative to the received signal. The search algorithms use the Sequential Probability Ratio Test (SPRT) to determine whether the received and locally generated code sequences are in phase. The speed of acquisition is increased by parallelism resulting from having a multi-fingered receiver. For example, in the described embodiment of the invention the main Pilot Rake 1711 has a total of 11 fingers representing a total phase period of 11 chip periods. For acquisition 8 separate sequential probability ratio tests (SPRTs) are implemented, with each SPRT observing a 4 chip window. Each window is offset from the previous window by one chip, and in a search sequence any given code phase is covered by 4 windows. If all 8 of the SPRT tests are rejected, then the set of windows is moved by 8 chips. If any of the SPRT's is accepted, then the code phase of the locally generated pilot code sequence is adjusted to attempt to center the accepted SPRT's phase within the Pilot AVC. It is likely that more than one SPRT reaches the acceptance threshold at the same time. A table lookup is used cover all 256 possible combinations of accept/reject and the modem controller uses the information to estimate the correct center code phase within the Pilot Rake 1711. Each SPRT is implemented as follows (all operations occur at 64 k symbol rate): Denote the fingers' output level values as I_Finger[n] and Q_Finger[n], where n=0 . . . 10 (inclusive, 0 is earliest (most advanced) finger), then the power of each window is:

$$\text{Power Window}[i] = \sum_n (I\_Finger^2[n] + Q\_Finger^2[n])$$

To implement the SPRT's the modem controller then performs for each of the windows the following calculations which are expressed as a pseudo-code subroutine:

```
/* find bin for Power */
tmp = SIGMA[0] ;
for (k = 0; k < 3; k++) {
   if (Power > lambda [k]) tmp = SIGMA[k+1];
}
test_statistic += tmp; /* update statistic */
if(test_statistic > ACCEPTANCE_THRESHOLD)you've got ACQ;
else if (test_statistic < DISMISSAL_THRESHOLD) {
   forget this code phase;
} else keep trying - get more statistics;
```

where lambda[k] are as defined in the above section on quantile estimation, and SIGMA[k], ACCEPTANCE_THRESHOLD and DISMISSAL_THRESHOLD are predetermined constants. Note that SIGMA[k] is negative for values for low values of k, and positive for right values of k, such that the acceptance and dismissal thresholds can be constants rather than a function of how many symbols worth of data have been accumulated in the statistic.

The modem controller determines which bin delimited by the values of lambda[k] the Power level falls into which allows the modem controller to develop an approximate statistic.

For the present algorithm, the control voltage is formed as $\varepsilon = y^T By$, where y is a vector formed from the complex valued output values of the Pilot Vector correlator 1711, and B is a matrix consisting of the constant values pre-determined to maximize the operating characteristics while minimizing the noise as described previously with reference to the Quadratic Detector.

To understand the operation of the Quadratic Detector, it is useful to consider the following. A spread spectrum (CDMA) signal, s(t) is passed through a multipath channel with an impulse response $h_c(t)$. The baseband spread signal is described by equation (30).

$$s(t) = \sum_i C_i p(t - iT_c) \tag{30}$$

where C_i is a complex spreading code symbol, p(t) is a predefined chip pulse and T_c is the chip time spacing, where $T_c = 1/R_c$ and R_c is the chip rate.

The received baseband signal is represented by equation (31)

$$r(t) = \sum_i C_i q(t - iT_c - \tau) + n(t) \tag{31}$$

where $q(t) = p(t) * h_c(t)$, τ is an unknown delay and n(t) is additive noise. The received signal is processed by a filter, $h_R(t)$, so the waveform, x(t), to be processed is given by equation (32).

$$x(t) = \sum_i C_i f(t - iT_c - \tau) + z(t) \tag{32}$$

where $f(t) = q(t) * h_R(t)$ and $z(t) = n(t) * h_R(t)$.

In the exemplary receiver, samples of the received signal are taken at the chip rate, that is to say, $1/T_c$. These samples, $x(mT_c + \tau')$, are processed by an array of correlators that compute, during the r^{th} correlation period, the quantities given by equation (33)

$$v_k^{(r)} = \sum_{m=rL}^{rL+L-1} x(mT_c + \tau')\, C_{m+k}^{*} \tag{33}$$

These quantities are composed of a noise component $W_k^{(r)}$ and a deterministic component $y_k^{(r)}$ given by equation (34).

$$y_k^{(r)} = E[v_k^{(r)}] = Lf(kT_c + \tau' - \tau) \tag{34}$$

In the sequel, the time index r may be suppressed for ease of writing, although it is to be noted that the function f(t) changes slowly with time.

The samples are processed to adjust the sampling phase, τ', in an optimum fashion for further processing by the receiver, such as matched filtering. This adjustment is described below. To simplify the representation of the process, it is helpful to describe it in terms of the function $f(t+\tau)$, where the time-shift, τ, is to be adjusted. It is noted that the function $f(t+\tau)$ is measured in the presence of noise. Thus, it may be problematical to adjust the phase τ' based on measurements of the signal $f(t+\tau)$. To account for the noise, the function v(t): $v(t) = f(t) + m(t)$ is introduced, where the term m(t) represents a noise process. The system processor may be derived based on considerations of the function v(t).

The process is non-coherent and therefore is based on the envelope power function $|v(t+\tau)|^2$. The functional $e(\tau')$ given in equation (35) is helpful for describing the process.

$$e(\tau') = \int_{-\infty}^{0} |v(t + \tau' - \tau)|^2 dt - \int_{0}^{\infty} |v(t + \tau' - \tau)|^2 dt \tag{35}$$

The shift parameter is adjusted for $e(\tau') = 0$, which occurs when the energy on the interval $(-\infty, \tau' - \tau]$ equals that on the

interval $[\tau'-\tau,\infty)$. The error characteristic is monotonic and therefore has a single zero crossing point. This is the desirable quality of the functional. A disadvantage of the functional is that it is ill-defined because the integrals are unbounded when noise is present. Nevertheless, the functional $e(\tau')$ may be cast in the form given by equation (36).

$$e(\tau')=\int_{-\infty}^{\infty} w(t)|v(t+\tau'-\tau)|^2 dt \tag{36}$$

where the characteristic function w(t) is equal to sgn(t), the signum function.

To optimize the characteristic function w(t), it is helpful to define a figure of merit, F, as set forth in equation (37).

$$F=\frac{\overline{[e(\tau_0'+T_A)-e(\tau_0'-T_A)]^2}}{VAR\{e(\tau_0')\}} \tag{37}$$

The numerator of F is the numerical slope of the mean error characteristic on the interval $[-T_A,T_A]$ surrounding the tracked value, τ_0'. The statistical mean is taken with respect to the noise as well as the random channel, $h_c(t)$. It is desirable to specify a statistical characteristic of the channel in order to perform this statistical average. For example, the channel may be modeled as a Wide Sense Stationary Uncorrelated Scattering (WSSUS) channel with impulse response $h_c(t)$ and a white noise process U(t) that has an intensity function g(t) as shown in equation (38).

$$h_c(t)=\sqrt{g(t)}\ U(t) \tag{38}$$

The variance of $e(\tau)$ is computed as the mean square value of the fluctuation

$$e'(\tau)=e(\tau)-\langle e(\tau)\rangle \tag{39}$$

where $\langle e(\tau)\rangle$ is the average of $e(\tau)$ with respect to the noise.

Optimization of the figure of merit F with respect to the function w(t) may be carried out using well-known Variational methods of optimization.

Once the optimal w(t) is determined, the resulting processor may be approximated accurately by a quadratic sample processor which is derived as follows.

By the sampling theorem, the signal v(t), bandlimited to a bandwidth W may be expressed in terms of its samples as shown in equation (40).

$$v(t)=\Sigma v(k/W)\ \sin c[(Wt-k)\pi] \tag{40}$$

substituting this expansion into equation (z+6) results in an infinite quadratic form in the samples $v(k/W+\tau'-\tau)$. Making the assumption that the signal bandwidth equals the chip rate allows the use of a sampling scheme that is clocked by the chip clock signal to be used to obtain the samples. These samples, V_k are represented by equation (41).

$$v_k=v(kT_c+\tau'-\tau) \tag{41}$$

This assumption leads to a simplification of the implementation. It is valid if the aliasing error is small.

In practice, the quadratic form that is derived is truncated. An example normalized B matrix is given below in Table 12. For this example, an exponential delay spread profile $g(t)=\exp(-t/\tau)$ is assumed with τ equal to one chip. An aperture parameter T_A equal to one and one-half chips has also been assumed. The underlying chip pulse has a raised cosine spectrum with a 20% excess bandwidth.

TABLE 12

Example B matrix										
0	0	0	0	0	0	0	0	0	0	0
0	0	−0.1	0	0	0	0	0	0	0	0
0	−0.1	0.22	0.19	−0.19	0	0	0	0	0	0
0	0	0.19	1	0.45	−0.2	0	0	0	0	0
0	0	−0.19	0.45	0.99	0.23	0	0	0	0	0
0	0	0	−0.2	0.23	0	−0.18	0.17	0	0	0
0	0	0	0	0	−0.18	−0.87	−0.42	0.18	0	0
0	0	0	0	0	0.17	−0.42	−0.92	−0.16	0	0
0	0	0	0	0	0	0.18	−0.16	−0.31	0	0
0	0	0	0	0	0	0	0	0	−0.13	0
0	0	0	0	0	0	0	0	0	0	0

Code tracking is implemented via a loop phase detector that is implemented as follows. The vector y is defined as a column vector which represents the 11 complex output level values of the Pilot AVC **1711**, and B denotes an 11×11 symmetric real valued coefficient matrix with pre-determined values to optimize performance with the non-coherent Pilot AVC output values y. The output signal ϵ of the phase detector is given by equation (42):

$$\epsilon=y^T By \tag{42}$$

The following calculations are then performed to implement a proportional plus integral loop filter and the VCO:

$$x[n]=x[n-1]+\beta\epsilon$$

$$z[n]=z[n-1]+x[n]+\alpha\epsilon$$

for β and α which are constants chosen from modeling the system to optimize system performance for the particular transmission channel and application, and where x[n] is the loop filter's integrator output value and z[n] is the VCO output value. The code phase adjustments are made by the modem controller the following C-subroutine:

```
if (z > zmax) {
  delay phase 1/16 chip;
  z -= zmax;
} else if (z < -zmax) {
  advance phase 1/16 chip;
  z += zmax;
}
```

A different delay phase could be used in the above pseudo-code consistant with the present invention.

The AMF Tap-Weight Update Algorithm of the AMF Weight Gen **1722** occurs periodically to de-rotate and scale the phase of each finger value of the Pilot Rake **1711** by performing a complex multiplication of the Pilot AVC finger value with the complex conjugate of the current output value of the carrier tracking loop and applying the product to a low pass filter and form the complex conjugate of the filter values to produce AMF tap-weight values, which are periodically written into the AMF filters of the CDMA modem.

The lock check algorithm, shown in FIG. **17**, is implemented by the modem controller **1303** performing SPRT operations on the output signal of the scalar correlator array. The SPRT technique is the same as that for the acquisition algorithms, except that the acceptance and rejection thresholds are changed to increase the probability of detection of lock.

Carrier tracking is accomplished via a second order loop that operates on the pilot output values of the scalar correlated array. The phase detector output is the hard limited version of the quadrature component of the product of the

(complex valued) pilot output signal of the scalar correlated array and the VCO output signal. The loop filter is a proportional plus integral design. The VCO is a pure summation, accumulated phase error ϕ, which is converted to the complex phasor cos ϕ+j sin ϕ using a look-up table in memory.

The previous description of acquisition and tracking algorithm focuses on a non-coherent method because the acquisition and tracking algorithm described requires non-coherent acquisition following by non-coherent tracking because during acquisition a coherent reference is not available until the AMF, Pilot AVC, Aux AVC, and DPLL are in an equilibrium state. However, it is known in the art that coherent tracking and combining is always optimal because in non-coherent tracking and combining the output phase information of each Pilot AVC finger is lost. Consequently, another embodiment of the invention employs a two step acquisition and tracking system, in which the previously described non-coherent acquisition and tracking algorithm is implemented first, and then the algorithm switches to a coherent tracking method. The coherent combining and tracking method is similar to that described previously, except that the error signal tracked is of the form:

$$\epsilon = y^T A y \tag{43}$$

where y is defined as a column vector which represents the 11 complex output level values of the Pilot AVC 171 1, and A denotes an 11×11 symmetric real valued coefficient matrix with pre-determined values to optimize performance with the coherent Pilot AVC outputs y. An exemplary A matrix is shown below.

$$A = \begin{matrix} 1&0&0&0&0&0&0&0&0&0&0 \\ 0&1&0&0&0&0&0&0&0&0&0 \\ 0&0&1&0&0&0&0&0&0&0&0 \\ 0&0&0&1&0&0&0&0&0&0&0 \\ 0&0&0&0&1&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&-1&0&0&0&0 \\ 0&0&0&0&0&0&0&-1&0&0&0 \\ 0&0&0&0&0&0&0&0&-1&0&0 \\ 0&0&0&0&0&0&0&0&0&-1&-1 \\ 0&0&0&0&0&0&0&0&0&0&0 \end{matrix} \tag{44}$$

Referring to FIG. 9, the Video Distribution Controller Board (VDC) 940 of the RCS is connected to each MIU 931, 932, 933 and the RF Transmitters/Receivers 950. The VDC 940 is shown in FIG. 21. The Data Combiner Circuitry (DCC) 2150 includes a Data Demultiplexer 2101, Data Summer 2102, FIR Filters 2103, 2104, and a Driver 2111. The DCC 2150 1) receives the weighted CDMA modem I and Q data signal MDAT from each of the MIUs, 931, 932, 933, 2) sums the I and Q data with the digital bearer channel data from each MIU 931, 932, 933, 3) and sums the result with the broadcast data message signal BCAST and the Global Pilot spreading code GPILOT provided by the master modem 1210, 4) band shapes the summed signals for transmission, and 5) produces analog data signal for transmission to the RF Transmitter/Receiver.

FIR Filters 2103, 2104 are used to modify the MIU CDMA Transmit I and Q Modem Data before transmission. The WAC transfers FIR Filter Coefficient data through the Serial Port link 912 through the VDC Controller 2120 and to the FIR filters 2103, 2104. Each FIR Filter 2103, 2104 is Configured separately. The FIR Filters 2103, 2104 employ Up-Sampling to operate at twice the chip rate so zero data values are sent after every MIU CDMA Transmit Modem DATI and DATQ value to produce FTXI and FTXQ

The VDC 940 distributes the AGC signal AGCDATA from the AGC 1750 of the MIUs 931, 932, 933 to the RF

Transmitter/Receiver 950 through the Distribution interface (DI) 2110. The VDC DI 2110 receives data RXI and RXQ from the RF Transmitter/Receiver and distributes the signal as VDATAI and VDATAQ to MIUs 931, 932, 933.

Referring to FIG. 21, the VDC 940 also includes a VDC controller 2120 which monitors status and fault information signals MIUSTAT from MIUs and connects to the serial link 912 and HSBS 970 to communicate with WAC 920 shown in FIG. 9. The VDC controller 2120 includes a microprocessor, such as an Intel 8032 Microcontroller, an oscillator (not shown) providing timing signals, and memory (not shown). The VDC controller memory includes a Flash Prom (not shown) to contain the controller program code for the 8032 Microprocessor, and an SRAM (not shown) to contain the temporary data written to and read from memory by the microprocessor.

Referring to FIG. 9, the present invention includes a RF Transmitter/Receiver 950 and power amplifier section 960. Referring to FIG. 22 the RF Transmitter/Receiver 950 is divided into three sections: the transmitter module 2201, the receiver module 2202, and the Frequency Synthesizer 2203. Frequency Synthesizer 2203 produces a transmit carrier frequency TFREQ and a receive carrier frequency RFREQ in response to a Frequency control signal FREQCTRL received from the WAC 920 on the serial link 912. In the transmitter module 2201, the input analog I and Q data signals TXI and TXQ from the VDC applied to the Quadrature modulator 2220, which also receives a transmit carrier frequency signal TFREQ from the Frequency Synthesizer 2203 to produce a quadrature modulated transmit carrier signal TX. The analog transmit carrier modulated signal, an upconverted RF signal, TX is then applied to the Transmit Power Amplifier 2252 of the Power Amplifier 960. The amplified transmit carrier signal is then passed through the High Power Passive Components (HPPC) 2253 to the Antenna 2250, which transmits the upconverted RF signal to the communication channel as a CDMA RF signal. In one embodiment of the invention, the Transmit Power Amplifier 2252 comprises eight amplifiers of approximately 60 watts peak-to-peak each.

The HPPC 2253 comprises a lightning protector, an output filter, a 10 dB directional coupler, an isolator, and a high power termination attached to the isolator.

A receive CDMA RF signal is received at the antenna 2250 from the RF channel and passed through the HPPC 2253 to the Receive Power Amplifier 2251. The receive power amplifier 2251 includes, for example, a 30 watt power transistor driven by a 5 watt transistor. The RF receive module 2202 has quadrature modulated receive carrier signal RX from the receive power amplifier. The receive module 2202 includes a Quadrature demodulator 2210 which takes the receive carrier modulated signal RX and the receive carrier frequency signal RFREQ from the Frequency Synthesizer 2203, synchronously demodulates the carrier, and analog I and Q channels. These channels are filtered to produce the signals RXI and RXQ, which are transferred to the VDC 940.

The Subscriber Unit

FIG. 23 shows the Subscriber Unit (SU) of one embodiment of the present invention. As shown, the SU includes an RF section 2301 including a RF modulator 2302, RF demodulator 2303, and splitter/isolator 2304 which receive Global and Assigned logical channels including traffic and control messages and Global Pilot signals in the Forward link CDMA RF channel signal, and transmit Assigned Channels and Reverse Pilot signals in the Reverse Link

CDMA RF channel. The Forward and Reverse links are received and transmitted respectively through antenna 2305. The RF section employs, in one exemplary embodiment, a conventional dual conversion superheterodyne receiver having a synchronous demodulator responsive to the signal ROSC. Selectivity of such a receiver is provided by a 70 MHz transversal SAW filter (not shown). The RF modulator includes a synchronous modulator (not shown) responsive to the carrier signal TOSC to produce a quadrature modulated carrier signal. This signal is stepped up in frequency by an offset mixing circuit (not shown).

The SU further includes a Subscriber Line Interface 2310, including the functionality of a control (CC) generator, a Data Interface 2320, an ADPCM encoder 2321, an ADPCM decoder 2322, an SU controller 2330, an SU clock signal generator 2331, memory 2332, and a CDMA modem 2340, which is essentially the same as the CDMA modem 1210 described above with reference to FIG. 13. It is noted that data interface 2320, ADPCM Encoder 2321 and ADPCM Decoder 2322 are typically provided as a standard ADPCM Encoder/Decoder chip.

The Forward Link CDMA RF Channel signal is applied to the RF demodulator 2303 to produce the Forward link CDMA signal. The Forward Link CDMA signal is provided to the CDMA modem 2340, which acquires synchronization with the Global pilot signal, produces global pilot synchronization signal to the Clock 2331, to generate the system timing signals, and despreads the plurality of logical channels. The CDMA modem 2340 also acquires the traffic messages RMESS and control messages RCTRL and provides the traffic message signals RMESS to the Data Interface 2320 and receive control message signals RCTRL to the SU Controller 2330.

The receive control message signals RCTRL include a subscriber identification signal, a coding signal, and bearer modification signals. The RCTRL may also include control and other telecommunication signaling information. The receive control message signal RCTRL is applied to the SU controller 2330, which verifies that the call is for the SU from the Subscriber identification value derived from RCTRL. The SU controller 2330 determines the type of user information contained in the traffic message signal from the coding signal and bearer rate modification signal. If the coding signal indicates the traffic message is ADPCM coded, the traffic message RVMESS is sent to the ADPCM decoder 2322 by sending a select message to the Data Interface 2320. The SU controller 2330 outputs an ADPCM coding signal and bearer rate signal derived from the coding signal to the ADPCM decoder 2322. The traffic message signal RVMESS is the input signal to the ADPCM decoder 2322, where the traffic message signal is converted to a digital information signal RINF in response to the values of the input ADPCM coding signal.

If the SU controller 2330 determines the type of user information contained in the traffic message signal from the coding signal is not ADPCM coded, then RDMESS passes through the ADPCM encoder transparently. The traffic message RDMESS is transferred from the Data Interface 2320 directly to the Interface Controller (IC) 2312 of the subscriber line interface 2310.

The digital information signal RINF or RDMESS is applied to the subscriber line interface 2310, including a interface controller (IC) 2312 and Line Interface (LI) 2313. For the exemplary embodiment the IC is an Extended PCM Interface Controller (EPIC) and the LI is a Subscriber Line Interface Circuit (SLIC) for POTS which corresponds to RINF type signals, and a ISDN Interface for ISDN which corresponds to RDMESS type signals. The EPIC and SLIC circuits are well known in the art. The subscriber line interface 2310 converts the digital information signal RINF or RDMESS to the user defined format. The user defined format is provided to the IC 2312 from the SU Controller 2330. The LI 2310 includes circuits for performing such functions as A-law or μ-law conversion, generating dial tone and, and generating or interpreting signaling bits. The line interface also produces the user information signal to the SU User 2350 as defined by the subscriber line interface, for example POTS voice, voiceband data or ISDN data service.

For a Reverse Link CDMA RF Channel, a user information signal is applied to the LI 2313 of the subscriber line interface 2310, which outputs a service type signal and an information type signal to the SU controller. The IC 2312 of the subscriber line interface 2310 produces a digital information signal TINF which is the input signal to the ADPCM encoder 2321 if the user information signal is to be ADPCM encoded, such as for POTS service. For data or other non-ADPCM encoded user information, the IC 2312 passes the data message TDMESS directly to the Data Interface 2320. The Call control module (CC), including in the subscriber line interface 2310, derives call control information from the User information signal, and passes the call control information CCINF to the SU controller 2330. The ADPCM encoder 2321 also receives coding signal and bearer modification signals from the SU controller 2330 and converts the input digital information signal into the output message traffic signal TVMESS in response to the coding and bearer modification signals. The SU controller 2330 also outputs the reverse control signal which includes the coding signal call control information, and bearer channel modification signal, to the CDMA modem. The output message signal TVMESS is applied to the Data Interface 2320. The Data Interface 2320 sends the user information to the CDMA modem 2340 as transmit message signal TMESS. The CDMA modem 2340 spreads the output message and reverse control channels TCTRL received from the SU controller 2330, and produces the reverse link CDMA Signal. The Reverse Link CDMA signal is provided to the RF transmit section 2301 and modulated by the RF modulator 2302 to produce the output Reverse Link CDMA RF channel signal transmitted from antenna 2305.

Call Connection and Establishment Procedure

The process of bearer channel establishment consists of two procedures: the call connection process for a call connection incoming from a remote call processing unit such as an RDU (Incoming Call Connection), and the call connection process for a call outgoing from the SU (Outgoing Call Connection). Before any bearer channel can be established between an RCS and a SU, the SU must register its presence in the network with the remote call processor such as the RDU. When the off-hook signal is detected by the SU, the SU not only begins to establish a bearer channel; but also initiates the procedure for an RCS to obtain a terrestrial link between the RCS and the remote processor. As incorporated herein by reference, the process of establishing the RCS and RDU connection is detailed in the DECT V5.1 standard.

For the Incoming Call Connection procedure shown in FIG. 24, first 2401, the WAC 920 (shown in FIG. 9) receives, via one of the MUXs 905, 906 and 907, an incoming call request from a remote call processing unit. This request identifies the target SU and that a call connection to the SU is desired. The WAC periodically outputs the SBCH channel

with paging indicators for each SU and periodically outputs the FBCH traffic lights for each access channel. In response to the incoming call request, the WAC, at step 2420, first checks to see if the identified SU is already active with another call. If so, the WAC returns a busy signal for the SU to the remote processing unit through the MUX, otherwise the paging indicator for the channel is set.

Next, at step 2402, the WAC checks the status of the RCS modems and, at step 2421, determines whether there is an available modem for the call. If a modem is available, the traffic lights on the FBCH indicate that one or more AXCH channels are available. If no channel is available after a certain period of time, then the WAC returns a busy signal for the SU to the remote processing unit through the MUX. If an RCS modem is available and the SU is not active (in Sleep mode), the WAC sets the paging indicator for the identified SU on the SBCH to indicate an incoming call request. Meanwhile, the access channel modems continuously search for the Short Access Pilot signal (SAXPT) of the SU.

At step 2403, an SU in Sleep mode periodically enters awake mode. In awake mode, the SU modem synchronizes to the Downlink Pilot signal, waits for the SU modem AMF filters and phase locked loop to settle, and reads the paging indicator in the slot assigned to it on the SBCH to determine if there is a call for the SU 2422. If no paging indicator is set, the SU halts the SU modem and returns to sleep mode. If a paging indicator is set for an incoming call connection, the SU modem checks the service type and traffic lights on FBCH for an available AXCH.

Next, at step 2404, the SU modem selects an available AXCH and starts a fast transmit power ramp-up on the corresponding SAXPT. For a period the SU modem continues fast power ramp-up on SAXPT and the access modems continue to search for the SAXPT.

At step 2405, the RCS modem acquires the SAXPT of the SU and begins to search for the SU LAXPT. When the SAXPT is acquired, the modem informs the WAC controller, and the WAC controller sets the traffic lights corresponding to the modem to "red" to indicate the modem is now busy. The traffic lights are periodically output while continuing to attempt acquisition of the LAXPT.

The SU modem monitors, at step 2406, the FBCH AXCH traffic light. When the AXCH traffic light is set to red, the SU assumes the RCS modem has acquired the SAXPT and begins transmitting LAXPT. The SU modem continues to ramp-up power of the LAXPT at a slower rate until Sync-Ind messages are received on the corresponding CTCH. If the SU is mistaken because the traffic light was actually set in response to another SU acquiring the AXCH, the SU modem times out because no Sync-Ind messages are received. The SU randomly waits a period of time, picks a new AXCH channel, and steps 2404 and 2405 are repeated until the SU modem receives Sync-Ind messages. Details of the power ramp up method used in the exemplary embodiment of this invention may be found in the U.S. patent application entitled METHOD OF CONTROLLING INITIAL POWER RAMP-UP IN CDMA SYSTEMS BY USING SHORT CODES filed on even date herewith, which is hereby incorporated by reference.

Next, at step 2407, the RCS modem acquires the LAXPT of the SU and begins sending Sync-Ind messages on the corresponding CTCH. The modem waits 10 msec for the Pilot and AUX Vector correlator filters and Phase locked loop to settle, but continues to send Synch-Ind messages on the CTCH. The modem then begins looking for a request

message for access to a bearer channel (MAC_ACC_REQ), from the SU modem.

The SU modem, at step 2408, receives the Sync-Ind message and freezes the LAXPT transmit power level. The SU modem then begins sending repeated request messages for access to a bearer traffic channel (MAC_ACC_REQ) at fixed power levels, and listens for a request confirmation message (MAC_BEARER_CFM) from the RCS modem.

Next, at step 2409, the RCS modem receives a MAC_ACC_REQ message; the modem then starts measuring the AXCH power level, and starts the APC channel. The RCS modem then sends the MAC_BEARER_CFM message to the SU and begins listening for the acknowledgment MAC_BEARER_CFM_ACK of the MAC_BEARER_CFM message.

At step 2410, the SU modem receives the MAC_BEARER_CFM message and begins obeying the APC power control messages. The SU stops sending the MAC_ACC_REQ message and sends the RCS modem the MAC_BEARER_CFM_ACK message. The SU begins sending the null data on the AXCH. The SU waits 10 msec for the uplink transmit power level to settle.

The RCS modem, at step 2411, receives the MAC_BEARER_CFM_ACK message and stops sending the MAC_BEARER_CFM messages. APC power measurements continue.

Next, at step 2412, both the SU and the RCS modems have synchronized the sub-epochs, obey APC messages, measure receive power levels, and compute and send APC messages. The SU waits 10 msec for downlink power level to settle.

Finally, at step 2413, Bearer channel is established and initialized between the SU and RCS modems. The WAC receives the bearer establishment signal from the RCS modem, re-allocates the AXCH channel and sets the corresponding traffic light to green.

For the Outgoing Call Connection shown in FIG. 25, the SU is placed in active mode by the off-hook signal at the user interface at step 2501.

Next, at step 2502, the RCS indicates available AXCH channels by setting the respective traffic lights.

At step 2503, the SU synchronizes to the Downlink Pilot, waits for the SU modem Vector correlator filters and phase lock loop to settle, and the SU checks service type and traffic lights for an available AXCH.

Steps 2504 through 2513 are identical to the procedure steps 2404 through 2413 for the Incoming Call Connection procedure of FIG. 24, and so are not explained in detail.

In the previous procedures for Incoming Call Connection and Outgoing Call Connection, the power Ramping-Up process consists of the following events. The SU starts from very low transmit power and increases its power level while transmitting the short code SAXPT; once the RCS modem detects the short code it turns off the traffic light. Upon detecting the changed traffic light, the SU continues ramping-up at a slower rate this time sending the LAXPT. Once the RCS modem acquires the LAXPT and sends a message on CTCH to indicate this, the SU keeps its transmit (TX) power constant and sends the MAC-Access-Request message. This message is answered with a MAC_BEARER_CFM message on the CTCH. Once the SU receives the MAC_BEARER_CFM message it switches to the traffic channel (TRCH) which is the dial tone for POTS.

When the SU captures a specific user channel AXCH, the RCS assigns a code seed for the SU through the CTCH. The

code seed is used by the spreading code generator in the SU modem to produce the assigned code for the reverse pilot of the subscriber, and the spreading codes for associated channels for traffic, call control, and signaling. The SU reverse pilot spreading code sequence is synchronized in phase to the RCS system Global Pilot spreading code sequence, and the traffic, call control, and signaling spreading codes are synchronized in phase to the SU reverse pilot spreading code sequence.

If the Subscriber unit is successful in capturing a specific user channel, the RCS establishes a terrestrial link with the remote processing unit to correspond to the specific user channel. For the DECT V5.1 standard, once the complete link from the RDU to the LE is established using the V5.1 ESTABLISHMENT message, a corresponding V5.1 ESTABLISHMENT ACK message is returned from the LE to the RDU, and the Subscriber Unit is sent a CONNECT message indicating that the transmission link is complete.

Support of Special Service Types

The system of the present invention includes a bearer channel modification feature which allows the transmission rate of the user information to be switched from a lower rate to a maximum of 64 kb/s. The Bearer Channel Modification (BCM) method is used to change a 32 kb/s ADPCM channel to a 64 kb/s PCM channel to support high speed data and fax communications through the spread-spectrum communication system of the present invention. Additional details of this technique are described in U.S. patent application entitled "CDMA COMMUNICATION SYSTEM WHICH SELECTIVELY SUPPRESSES DATA TRANSMISSION-ING DURING ESTABLISHMENT OF A COMMUNICATION CHANNEL" filed on even date herewith and incorporated herein by reference.

First, a bearer channel on the RF interface is established between the RCS and SU, and a corresponding link exists between the RCS terrestrial interface and the remote processing unit, such as an RDU. The digital transmission rate of the link between the RCS and remote processing unit normally corresponds to a data encoded rate, which may be, for example, ADPCM at 32 kb/s. The WAC controller of the RCS monitors the encoded digital data information of the link received by the Line Interface of the MUX. If the WAC controller detects the presence of the 2100 Hz tone in the digital data, the WAC instructs the SU through the assigned logical control channel and causes a second, 64 kb/s duplex link to be established between the RCS modem and the SU. In addition, the WAC controller instructs the remote processing unit to establish a second 64 kb/s duplex link between the remote processing unit and the RCS. Consequently, for a brief period, the remote processing unit and the SU exchange the same data over both the 32 kb/s and the 64 kb/s links through the RCS. Once the second link is established, the remote processing unit causes the WAC controller to switch transmission only to the 64 kb/s link, and the WAC controller instructs the RCS modem and the SU to terminate and tear down the 32 kb/s link. Concurrently, the 32 kb/s terrestrial link is also terminated and torn down.

Another embodiment of the BCM method incorporates a negotiation between the external remote processing unit, such as the RDU, and the RCS to allow for redundant channels on the terrestrial interface, while only using one bearer channel on the RF interface. The method described is a synchronous switchover from the 32 kb/s link to the 64 kb/s link over the air link which takes advantage of the fact that the spreading code sequence timing is synchronized between the RCS modem and SU. When the WAC controller detects the presence of the 2100 Hz tone in the digital data, the WAC controller instructs the remote processing unit to establish a second 64 kb/s duplex link between the remote processing unit and the RCS. The remote processing unit then sends 32 kb/s encoded data and 64 kb/s data concurrently to the RCS. Once the remote processing unit has established the 64 kb/s link, the RCS is informed and the 32 kb/s link is terminated and torn down. The RCS also informs the SU that the 32 kb/s link is being torn down and to switch processing to receive unencoded 64 kb/s data on the channel. The SU and RCS exchange control messages over the bearer control channel of the assigned channel group to identify and determine the particular subepoch of the bearer channel spreading code sequence within which the RCS will begin transmitting 64 kbit/sec data to the SU. Once the subepoch is identified, the switch occurs synchronously at the identified subepoch boundary. This synchronous switchover method is more economical of bandwidth since the system does not need to maintain capacity for a 64 kb/s link in order to support a switchover.

The previously described embodiments of the BCM feature, the RCS will tear down the 32 kb/s link first, but one skilled in the art would know that the RCS could tear down the 32 kb/s link after the bearer channel has switched to the 64 kb/s link.

As another special service type, the system of the present invention includes a method for conserving capacity over the RF interface for ISDN types of traffic. This conservation occurs while a known idle bit pattern is transmitted in the ISDN D-channel when no data information is being transmitted. The CDMA system of the present invention includes a method to prevent transmission of redundant information carried on the D-channel of ISDN networks for signals transmitted through a wireless communication link. The advantage of such method is that it reduces the amount of information transmitted and consequently the transmit power and channel capacity used by that information. The method is described as it is used in the RCS. In the first step, the controller, such as the WAC of the RCS or the SU controller of the SU, monitors the output D-channel from the subscriber line interface for a pre-determined channel idle pattern. A delay is included between the output of the line interface and the CDMA modem. Once the idle pattern is detected, the controller inhibits the transmission of the spread message channel through a message included in the control signal to the CDMA modem. The controller continues to monitor the output D-channel of the line interface until the presence of data information is detected. When data information is detected, the spread message channel is activated. Because the message channel is synchronized to the associated pilot which is not inhibited, the corresponding CDMA modem of the other end of the communication link does not have to reacquire synchronization to the message channel.

Drop Out Recovery

The RCS and SU each monitor the CDMA bearer channel signal to evaluate the quality of the CDMA bearer channel connection. Link quality is evaluated using the sequential probability ratio test (SPRT) employing adaptive quantile estimation. The SPRT process uses measurements of the received signal power; and if the SPRT process detects that the local spreading code generator has lost synchronization with the received signal spreading code or if it detects the absence or low level of a received signal, the SPRT declares loss of lock (LOL).

When the LOL condition is declared, the receiver modem of each RCS and SU begins a Z-search of the input signal with the local spreading code generator. Z-search is well known in the art of CDMA spreading code acquisition and detection and is described in *Digital Communications and Spread Spectrum Systems*, by to Robert E. Ziemer and Roger L. Peterson, at pages 492–94 which is incorporated herein by reference. The Z-search algorithm of the present invention tests groups of eight spreading code phases ahead and behind the last known phase in larger and larger spreading code phase increments.

During the LOL condition detected by the RCS, the RCS continues to transmit to the SU on the Assigned Channels, and continues to transmit power control signals to the SU to maintain SU transmit power level. The method of transmitting power control signals is described below. Successful reacquisition desirably takes place within a specified period of time. If reacquisition is successful, the call connection continues, otherwise the RCS tears down the call connection by deactivating and deallocating the RCS modem assigned by the WAC, and transmits a call termination signal to a remote call processor, such as the RDU, as described previously.

When the LOL condition is detected by the SU, the SU stops transmission to the RCS on the Assigned Channels which forces the RCS into a LOL condition, and starts the reacquisition algorithm. If reacquisition is successful, the call connection continues, and if not successful, the RCS tears down the call connection by deactivating and deallocating the SU modem as described previously.

POWER CONTROL

General

The power control feature of the present invention is used to minimize the amount of transmit power used by an RCS and the SUs of the system, and the power control subfeature that updates transmit power during bearer channel connection is defined as automatic power control (APC). AC data is transferred from the RCS to an SU on the forward APC channel and from an SU to the RCS on the reverse APC channel. When there is no active data link between the two, the maintenance power control (MPC) subfeature updates the SU transmit power.

Transmit power levels of forward and reverse assigned channels and reverse global channels are controlled by the APC algorithm to maintain sufficient signal power to interference noise power ratio (SIR) on those channels, and to stabilize and minimize system output power. The present invention uses a closed loop power control mechanism in which a receiver decides that the transmitter should incrementally raise or lower its transmit power. This decision is conveyed back to the respective transmitter via the power control signal on the APC channel. The receiver makes the decision to increase or decrease the transmitter's power based on two error signals. One error signal is an indication of the difference between the measured and desired despread signal powers, and the other error signal is an indication of the average received total power.

As used in the described embodiment of the invention, the term near-end power control is used to refer to adjusting the transmitter's output power in accordance with the APC signal received on the APC channel from the other end. This means the reverse power control for the SU and forward power control for the RCS; and the term far-end APC is used to refer to forward power control for the SU and reverse power control for the RCS (adjusting the opposite end's transmit power).

In order to conserve power, the SU modem terminates transmission and powers-down while waiting for a call, defined as the sleep phase. Sleep phase is terminated by an awaken signal from the SU controller. The SU modem acquisition circuit automatically enters the reacquisition phase, and begins the process of acquiring the downlink pilot, as described previously.

Closed Loop Power Control Algorithms

The near-end power control consists of two steps: first, the initial transmit power is set; and second, the transmit power is continually adjusted according to information received from the far-end using APC.

For the SU, initial transmit power is set to a minimum value and then ramped up, for example, at a rate of 1 dB/ms until either a ramp-up timer expires (not shown) or the RCS changes the corresponding traffic light value on the FBCH to "red" indicating that the RCS has locked to the SU's short pilot SAXPT. Expiration of the timer causes the SAXPT transmission to be shut down, unless the traffic light value is set to red first, in which case the SU continues to ramp-up transmit power but at a much lower rate than before the "red" signal was detected.

For the RCS, initial transmit power is set at a fixed value, corresponding to the minimum value necessary for reliable operation as determined experimentally for the service type and the current number of system users. Global channels, such as Global Pilot or, FBCH, are always transmitted at the fixed initial power, whereas traffic channels are switched to APC.

The APC bits are transmitted as one bit up or down signals on the APC channel. In the described embodiment, the 64 kb/s APC data stream is not encoded or interleaved.

Far-end power control consists of the near-end transmitting power control information for the far-end to use in adjusting its transmit power.

The APC algorithm causes the RCS or the SU to transmit +1 if the following inequality holds, otherwise −1.

$$\alpha_1 e_1 - \alpha_2 e_2 > 0 \tag{45}$$

Here, the error signal e_1 is calculated as

$$e_1 = P_d - (1 + SNR_{REQ})P_N \tag{46}$$

where P_d is the despread signal plus noise power, P_N is the despread noise power, and SNR_{REQ} is the desired despread signal to noise ratio for the particular service type; and

$$e_2 = P_r - P_o \tag{47}$$

where P_r is a measure of the received power and P_o is the automatic gain control (AGC) circuit set point. The weights α_1 and α_2 in equation (33) are chosen for each service type and APC update rate.

Maintenance Power Control

During the sleep phase of the SU, the interference noise power of the CDMA RF channel may change. The present invention includes a maintenance power control feature (MPC) which periodically adjusts the SU's initial transmit power with respect to the interference noise power of the CDMA channel. The MPC is the process whereby the transmit power level of an SU is maintained within close

proximity of the minimum level for the RCS to detect the SU's signal. The MPC process compensates for low frequency changes in the required SU transmit power.

The maintenance control feature uses two global channels: one is called the status channel (STCH) on reverse link, and the other is called the check-up channel (CUCH) on forward link. The signals transmitted on these channels carry no data and they are generated the same way the short codes used in initial power ramp-up are generated. The STCH and CUCH codes are generated from a "reserved" branch of the global code generator.

The MPC process is as follows. At random intervals, the SU sends a symbol length spreading code periodically for 3 ms on the status channel (STCH). If the RCS detects the sequence, it replies by sending a symbol length code sequence within the next 3 ms on the check-up channel (CUCH). When the SU detects the response from the RCS, it reduces its transmit power by a particular step size. If the SU does not see any response from the RCS within that 3 ms period, it increases its transmit power by the step size. Using this method, the RCS response is transmitted at a power level that is enough to maintain a 0.99 detection probability at all SU's.

The rate of change of traffic load and the number of active users is related to the total interference noise power of the CDMA channel. The update rate and step size of the maintenance power update signal for the present invention is determined by using queuing theory methods well known in the art of communication theory, such as outlined in "*Fundamentals of Digital Switching*" (Plenum-New York) edited by McDonald and incorporated herein by reference. By modeling the call origination process as an exponential random variable with mean 6.0 mins, numerical computation shows the maintenance power level of a SU should be updated once every 10 seconds or less to be able to follow the changes in interference level using 0.5 dB step size. Modeling the call origination process as a Poisson random variable with exponential interarrival times, arrival rate of 2×10^{-4} per second per user, service rate of $1/360$ per second, and the total subscriber population is 600 in the RCS service area also yields by numerical computation that an update rate of once every 10 seconds is sufficient when 0.5 dB step size is used.

Maintenance power adjustment is performed periodically by the SU which changes from sleep phase to awake phase and performs the MPC process. Consequently, the process for the MPC feature is shown in FIG. 26 and is as follows: First, at step 2601, signals are exchanged between the SU and the RCS maintaining a transmit power level that is close to the required level for detection: the SU periodically sends a symbol length spreading code in the STCH, and the RCS periodically sends a symbol length spreading code in the CUCH as response.

Next, at step 2602, if the SU receives a response within 3 ms after the STCH message it sent, it decreases its transmit power by a particular step size at step 2603; but if the SU does not receive a response within 3 ms after the STCH message, it increases its transmit power by the same step size at step 2604.

The SU waits, at step 2605, for a period of time before sending another STCH message, this time period is determined by a random process which averages 10 seconds.

Thus, the transmit power of the STCH messages from the SU is adjusted based on the RCS response periodically, and the transmit power of the CUCH messages from the RCS is fixed.

Mapping of Power Control Signal to Logical Channels For APC

Power control signals are mapped to specified Logical Channels for controlling transmit power levels of forward and reverse assigned channels. Reverse global channels are also controlled by the APC algorithm to maintain sufficient signal power to interference noise power ratio (SIR) on those reverse channels, and to stabilize and minimize system output power. The present invention uses a closed loop power control method in which a receiver periodically decides to incrementally raise or lower the output power of the transmitter at the other end. The method also conveys that decision back to the respective transmitter.

TABLE 13

APC Signal Channel Assignments

Link Channels and Signals	Call/Connection Status	Power Control Method: Initial Value	Power Control Method: Continuous
Reverse link AXCH AXPT	Being Established	as determined by power ramping	APC bits in forward APC channel
Reverse link APC, OW, TRCH, pilot signal	In-Progress	level established during call set-up	APC bits in forward APC channel
Forward link APC, OW, TRCH	In-Progress	fixed value	APC bits in reverse APC channel

Forward and reverse links are independently controlled. For a call/connection in process, forward link (TRCHs APC, and OW) power is controlled by the APC bits transmitted on the reverse APC channel. During the call/connection establishment process, reverse link (AXCH) power is also controlled by the APC bits transmitted on the forward APC channel. Table 13 summarizes the specific power control methods for the controlled channels.

The required SIRs of the assigned channels TRCH, APC and OW and reverse assigned pilot signal for any particular SU are fixed in proportion to each other and these channels are subject to nearly identical fading, therefore, they are power controlled together.

Adaptive Forward Power Control

The AFPC process attempts to maintain the minimum required SIR on the forward channels during a call/connection. The AFPC recursive process, shown in FIG. 27, consists of the steps of having an SU form the two error signals e_1 and e_2 in step 2701 where

$$e_1=P_d-(1+SNR_{REQ})P_N \tag{36}$$

$$e_2=P_r-P_o \tag{37}$$

and P_d is the despread signal plus noise power, P_N is the despread noise power, SNR_{REQ} is the required signal to noise ratio for the service type, P_r is a measure of the total received power, and P_o is the AGC set point. Next, the SU modem forms the combined error signal $\alpha_1e_1+\alpha_2e_2$ in step 2702. Here, the weights α_1 and α_2 are chosen for each service type and APC update rate. In step 2703, the SU hard limits the combined error signal and forms a single APC bit. The SU transmits the APC bit to the RCS in step 2704 and RCS modem receives the bit in step 2705. The RCS increases or decreases its transmit power to the SU in step 2706 and the algorithm repeats starting from step 2701.

Adaptive Reverse Power Control

The ARPC process maintains the minimum desired SIR on the reverse channels to minimize the total system reverse output power, during both call/connection establishment and while the call/connection is in progress. The recursive ARPC process, shown in FIG. 28, begins at step 2801 where the RCS modem forms the two error signals e_1 and e_2 in step 2801 where

$$e_1=P_d-(1+SNR_{REQ})P_N \tag{38}$$

$$e_2P_{rt}-P_o \tag{39}$$

and P_d is the despread signal plus noise power, P_N is the despread noise power, SNR_{REQ} is the desired signal to noise ratio for the service type, P_{rt} is a measure of the average total power received by the RCS, and P_o is the AGC set point. The RCS modem forms the combined error signal $\alpha_1 e_1+\alpha_2 e_2$ in step 2802 and hard limits this error signal to determine a single APC bit in step 2803. The RCS transmits the APC bit to the SU in step 2804, and the bit is received by the SU in step 2805. Finally, the SU adjusts its transmit power according to the received APC bit in step 2806, and the algorithm repeats starting from step 2801.

Rate (BER) in the Uplink and Downlink APC channels, which minimizes capacity devoted to the APC.

The power step up/down indicated by an APC bit is nominally between 0.1 and 0.01 dB. The dynamic range for power control is 70 dB on the reverse link and 12 dB on the forward link for the exemplary embodiment of the present system.

Alternative Embodiment of Multiplexing of APC Information

The dedicated APC and OW logical channels described previously can also be multiplexed together in one logical channel. The APC information is transmitted at 64 kb/s, continuously whereas the OW information occurs in data bursts. The alternative multiplexed logical channel includes the unencoded, non-interleaved 64 kb/s. APC information on, for example, the In-phase channel and the OW information on the Quadrature channel of the QPSK signal.

Closed Loop Power Control Implementation

The closed loop power control during a call connection responds to two different variations in overall system power. First, the system responds to local behavior such as changes in power level of an SU, and second, the system responds to changes in the power level of the entire group of active users in the system.

TABLE 14

Symbols/Thresholds Used for APC Computation

Service or Call Type	Call/Connection Status	Symbol (and Threshold) Used for APC Decision
Don't care	Being Established	AXCH
ISDN D SU	In-Progress	one 1/64-kb/s symbol from TRCH (ISDN-D)
ISDN 1B + D SU	In-Progress	TRCH (ISDN-B)
ISDN 2B + D SU	In-Progress	TRCH (one ISDN-B)
POTS SU (64 KBPS PCM)	In-Progress	one 1/64-KBPS symbol from TRCH, use 64 KBPS PCM threshold
POTS SU (32 KBPS ADPCM)	In-Progress	one 1/64-KBPS symbol from TRCH, use 32 KBPS ADPCM threshold
Silent Maintenance Call (any SU)	In-Progress	OW (continuous during a maintenance call)

SIR and Multiple Channel Types

The required SIR for channels on a link is a function of channel format (e.g. TRCH, OW), service type (e.g. ISDN B, 32 KBPS ADPCM POTS), and the number of symbols over which data bits are distributed (e.g. two 64 kb/s symbols are integrated to form a single 32 kb/s ADPCM POTS symbol). Despreader output power corresponding to the required SIR for each channel and service type is predetermined. While a call/connection is in progress, several user CDMA logical channels are concurrently active; each of these channels transfers a symbol every symbol period. The SIR of the symbol from the nominally highest SIR channel is measured, compared to a threshold and used to determine the APC step up/down decision each symbol period. Table 14 indicates the symbol (and threshold) used for the APC computation by service and call type.

APC Parameters

APC information is always conveyed as a single bit of information, and the APC Data Rate is equivalent to the APC Update Rate. The APC update rate is 64 kb/s. This rate is high enough to accommodate expected Rayleigh and Doppler fades, and allow for a relatively high (~0.2) Bit Error

The Power Control system of the exemplary embodiment of the present invention is shown in FIG. 29. As shown, the circuitry used to adjust the transmitted power is similar for the RCS (shown as the RCS power control module 2901) and SU (shown as the SU power control module 2902). Beginning with the RCS power control module 2901, the reverse link RF channel signal is received at the RF antenna and demodulated to produce the reverse CDMA signal RMCH. The signal RMCH is applied to the variable gain amplifier (VGA1) 2910 which produces an input signal to the Automatic Gain Control (AGC) Circuit 2911. The AGC 2911 produces a variable gain amplifier control signal into the VGA1 2910. This signal maintains the level of the output signal of VGA1 2910 at a near constant value. The output signal of VGA1 is despread by the despread-demultiplexer (demux) 2912, which produces a despread user message signal MS and a forward APC bit. The forward APC bit is applied to the integrator 2913 to produce the Forward APC control signal. The Forward APC control signal controls the Forward Link VGA2 2914 and maintains the Forward Link RF channel signal at a minimum desired level for communication.

The signal power of the despread user message signal MS of the RCS power module 2901 is measured by the power

measurement circuit 2915 to produce a signal power indication. The output of the VGA1 is also despread by the AUX despreader which despreads the signal by using an uncorrelated spreading code, and hence obtains a despread noise signal. The power measurement of this signal is multiplied by 1 plus the desired signal to noise ratio (SNR_R) to form the threshold signal S1. The difference between the despread signal power and the threshold value S1 is produced by the subtracter 2916. This difference is the error signal ES1, which is an error signal relating to the particular SU transmit power level. Similarly, the control signal for the VGA1 2910 is applied to the rate scaling circuit 2917 to reduce the rate of the control signal for VGA1 2910. The output signal of scaling circuit 2917 is a scaled system power level signal SP1. The Threshold Compute logic 2918 calculates the System Signal Threshold value SST from the RCS user channel power data signal RCSUSR. The complement of the Scaled system power level signal, SP1, and the System Signal Power Threshold value SST are applied to the adder 2919 which produces second error signal ES2. This error signal is related to the system transmit power level of all active SUs. The input Error signals ES1 and ES2are combined in the combiner 2920 produce a combined error signal input to the delta modulator (DM1) 2921, and the output signal of the DM1 is the reverse APC bit stream signal, having bits of value +1 or −1, which for the present invention is transmitted as a 64 kb/sec signal.

The Reverse APC bit is applied to the spreading circuit 2922, and the output signal of the spreading circuit 2922 is the spread-spectrum forward APC message signal. Forward OW and Traffic signals are also provided to spreading circuits 2923, 2924, producing forward traffic message signals 1, 2, . . . N. The power level of the forward APC signal, the forward OW, and traffic message signals are adjusted by the respective amplifiers 2925, 2926 and 2927 to produce the power level adjusted forward APC, OW, and TRCH channels signals. These signals are combined by the adder 2928 and applied to the VAG2 2914, which produces forward link RF channel signal.

The forward link RF channel signal including the spread forward APC signal is received by the RF antenna of the SU, and demodulated to produce the forward CDMA signal FMCH. This signal is provided to the variable gain amplifier (VGA3) 2940. The output signal of VGA3 is applied to the Automatic wax Gain Control Circuit (AGC) 2941 which produces a variable gain amplifier control signal to VGA3 2940. This signal maintains the level of the output signal of VGA3 at a near constant level. The output signal of VAG3 2940 is despread by the despread demux 2942, which produces a despread user message signal SUMS and a reverse APC bit. The reverse APC bit is applied to the integrator 2943 which produces the Reverse APC control signal. This reverse APC control signal is provided to the Reverse APC VGA4 2944 to maintain the Reverse link RF channel signal at a minimum power level.

The despread user message signal SUMS is also applied to the power measurement circuit 2945 producing a power measurement signal, which is added to the complement of threshold value S2 in the adder 2946 to produce error signal ES3. The signal ES3 is an error signal relating to the RCS transmit power level for the particular SU. To obtain threshold S2, the despread noise power indication from the AUX despreader is multiplied by 1 plus the desired signal to noise ratio SNR_R. The AUX despreader despreads the input data using an uncorrelated spreading code, hence its output is an indication of the despread noise power.

Similarly, the control signal for the VGA3 is applied to the rate scaling circuit to reduce the rate of the control signal for VGA3 in order to produce a scaled received power level RP1 (see FIG. 29). The threshold compute circuit computes the received signal threshold RST from the SU measured power signal SUUSR. The complement of the scaled received power level RP1 and the received signal threshold RST are applied to the adder which produces error signal ES4. This error is related to the RCS transmit power to all other SUs. The input error signals ES3 and ES4 are combined in the combiner and input to the delta modulator DM2 2947. The output signal of DM2 2947 is the forward APC bit stream signal, with bits having value of value +1 or −1. In the exemplary embodiment of the present invention, this signal is transmitted as a 64 kb/sec signal.

The Forward APC bit stream signal is applied to the spreading circuit 2948, to produce the output reverse spread-spectrum APC signal. Reverse OW and Traffic signals are also input to spreading circuits 2949, 2950, producing reverse OW and traffic message signals 1, 2, . . . , N, and the reverse pilot is generated by the reverse pilot generator 2951. The power level of the reverse APC message signal, reverse OW message signal, reverse pilot, and the reverse traffic message signals are adjusted by amplifiers 2952, 2953, 2954, 2955 to produce the signals which are combined by the adder 2956 and input to the reverse APC VGA4 2944. It is this VGA4 2944 which produces the reverse link RF channel signal.

During the call connection and bearer channel establishment process, the closed loop power control of the present invention is modified, and is shown in FIG. 30. As shown, the circuits used to adjust the transmitted power are different for the RCS, shown as the Initial RCS power control module 3001; and for the SU, shown as the Initial SU power control module 3002. Beginning with the Initial RCS power control module 3001, the reverse link RF channel signal is received at the RF antenna and demodulated producing the reverse CDMA signal IRMCH which is received by the first variable gain amplifier (VGA1) 3003. The output signal of VGA1 is detected by the Automatic Gain Control Circuit (AGC1) 3004 which provides a variable gain amplifier control signal to VGA1 3003 to maintain the level of the output signal of VAG1 at a near constant value. The output signal of VGA1 is despread by the despread demultiplexer 3005, which produces a despread user message signal IMS. The Forward APC control signal, ISET, is set to a fixed value, and is applied to the Forward Link Variable Gain Amplifier (VGA2) 3006 to set the Forward Link RF channel signal at a predetermined level.

The signal power of the despread user message signal IMS of the Initial RCS power module 3001 is measured by the power measure circuit 3007, and the output power measurement is subtracted from a threshold value S3 in the subtracter 3008 to produce error signal ES5, which is an error signal relating to the transmit power level of a particular SU. The threshold S3 is calculated by multiplying the despread power measurement obtained from the AUX despreader by 1 plus the desired signal to noise ratio SNR_R. The AUX despreader despreads the signal using an uncorrelated spreading code, hence its output signal is an indication of despread noise power. Similarly, the VGA1 control signal is applied to the rate scaling circuit 3009 to reduce the rate of the VGA1 control signal in order to produce a scaled system power level signal SP2. The threshold computation logic 3010 determines an Initial System Signal Threshold value (ISST) computed from the user channel power data signal (IRCSUSR). The complement of the Scaled system power level signal SP2 and the ISST are provided to the adder 3011 which produces a second error signal ES6, which

is an error signal relating to the system transmit power level of all active SUs. The value of ISST is the desired transmit power for a system having the particular configuration. The input Error signals ES5 and ES6 are combined in the combiner **3012** produce a combined error signal input to the delta modulator (DM3) **3013**. DM3 produces the initial reverse APC bit stream signal, having bits of value +1 or −1, which in the exemplary embodiment is transmitted as a 64 kb/s signal.

The Reverse APC bit stream signal is applied to the spreading circuit **3014**, to produce the initial spread-spectrum forward APC signal. The CTCH information is spread by the spreader **3016** to form the spread CTCH message signal. The spread APC and CTCH signals are scaled by the amplifiers **3015** and **3017**, and combined by the combiner **3018**. The combined signal is applied to VAG2 **3006**, which produces the forward link RF channel signal.

The forward link RF channel signal including the spread forward APC signal is received by the RF antenna of the SU and demodulated to produce the initial forward CDMA signal (IFMCH) which is applied to the variable gain amplifier (VGA3) **3020**. The output signal of VGA3 is detected by the Automatic Gain Control Circuit (AGC2) **3021** which produces a variable gain amplifier control signal for the VGA3 **3020**. This signal maintains the output power level of the VGA3 **3020** at a near constant value. The output signal of VAG3 is despread by the despread demultiplexer **3022**, which produces an initial reverse APC bit that is dependent on the output level of VGA3. The reverse APC bit is processed by the integrator **3023** to produce the Reverse APC control signal. The Reverse APC control signal is provided to the Reverse APC VGA4 **3024** to maintain Reverse link RF channel signal at a defined power level.

The global channel AXCH signal is spread by the spreading circuits **3025** to provide the spread AXCH channel signal. The reverse pilot generator **3026** provides a reverse pilot signal, and the signal power of AXCH and the reverse pilot signal are adjusted by the respective amplifiers **3027** and **3028**. The spread AXCH channel signal and the reverse pilot signal are summed by the adder **3029** to produce reverse link CDMA signal. The reverse link CDMA signal is received by the reverse APC VGA4 **3024**, which produces the reverse link RF channel signal output to the RF transmitter.

System Capacity Management

The system capacity management algorithm of the present invention optimizes the maximum user capacity for an RCS area, called a cell. When the SU comes within a certain value of maximum transmit power, the SU sends an alarm message to the RCS. The RCS sets the traffic lights which control access to the system, to "red" which, as previously described, is a flag that inhibits access by the SU's. This condition remains in effect until the call to the alarming SU terminates, or until the transmit power of the alarming SU, measured at the SU, is a value less than the maximum transmit power. When multiple SUs send alarm messages, the condition remains in effect until either all calls from alarming SUs terminate, or until the transmit power of the alarming SU, measured at the SU, is less than the maximum transmit power. An alternative embodiment monitors the bit error rate measurements from the FEC decoder, and holds the RCS traffic lights at "red" until the bit error rate is less than a predetermined value.

The blocking strategy of the present invention includes a method which uses the power control information transmitted from the RCS to an SU, and the received power measurements at the RCS. The RCS measures its transmit power level, detects that a maximum value is reached, and determines when to block new users. An SU preparing to enter the system blocks itself if the SU reaches the maximum transmit power before successful completion of a bearer channel assignment.

Each additional user in the system has the effect of increasing the noise level for all other users, which decreases the signal to noise ratio (SNR) that each user experiences. The power control algorithm maintains a desired SNR for each user. Therefore, in the absence of any other limitations, addition of a new user into the system has only a transient effect and the desired SNR is regained.

The transmit power measurement at the RCS is done by measuring either the root mean square (rms) value of the baseband combined signal or by measuring the transmit power of the RF signal and feeding it back to digital control circuits. The transmit power measurement may also be made by the SUs to determine if the unit has reached its maximum transmit power. The SU transmit power level is determined by measuring the control signal of the RF amplifier, and scaling the value based on the service type, such as POTS, FAX, or ISDN.

The information that an SU has reached the maximum power is transmitted to the RCS by the SU in a message on the Assigned Channels. The RCS also determines the condition by measuring reverse APC changes because, if the RCS sends APC messages to the SU to increase SU transmit power, and the SU transmit power measured at the RCS is not increased, the SU has reached the maximum transmit power.

The RCS does not use traffic lights to block new users who have finished ramping-up using the short codes. These users are blocked by denying them the dial tone and letting them time out. The RCS sends all 1's (go down commands) on the APC Channel to make the SU lower its transmit power. The RCS also sends either no CTCH message or a message with an invalid address which would force the FSU to abandon the access procedure and start over. The SU, however, does not start the acquisition process immediately because the traffic lights are red.

When the RCS reaches its transmit power limit, it enforces blocking in the same manner as when an SU reaches its transmit power limit. The RCS turns off all the traffic lights on the FBCH, starts sending all 1 APC bits (go down commands) to those users who have completed their short code ramp-up but have not yet been given a dial tone, and either sends no CTCH message to these users or sends messages with invalid addresses to force them to abandon the access process.

The self blocking process of the SU is as follows. When the SU starts transmitting the AXCH, the APC starts its power control operation using the AXCH and the SU transmit power increases. While the transmit power is increasing under the control of the APC, it is monitored by the SU controller. If the transmit power limit is reached, the SU abandons the access procedure and starts over.

System Synchronization

The RCS is synchronized either to the PSTN Network Clock signal through one of the Line interfaces, as shown in FIG. **10**, or to the RCS system clock oscillator, which free-runs to provide a master timing signal for the system. The Global Pilot Channel, and therefore all Logical channels within the CDMA channel, are synchronized to the system

clock signal of the RCS. The Global Pilot (GLPT) is transmitted by the RCS and defines the timing at the RCS transmitter.

The SU receiver is synchronized to the GLPT, and so behaves as a slave to the Network Clock oscillator. However, the SU timing is retarded by the propagation delay. In the present embodiment of the invention, the SU modem to extracts a 64 KHz and 8 KHz clock signal from the CDMA RF Receive channel, and a PLL oscillator circuit creates 2 MHz and 4 MHz clock signals

The SU transmitter and hence the LAXPT or ASPT are slaved to the timing of the SU receiver.

The RCS receiver is synchronized to the LAXPT or the ASPT transmitted by the SU, however, its timing may be retarded by the propagation delay. Hence, the timing of the RCS receiver is that of the RCS transmitter retarded by twice the propagation delay.

Furthermore, the system can be synchronized via a reference received from a Global Positioning System receiver (GPS). In a system of this type, a GPS receiver in each RCS provides a reference clock signal to all submodules of the RCS. Because each RCS receives the same time reference from the GPS, all of the system clock signals in all of the RCSs are synchronized.

Although the invention has been described in terms of multiple exemplary embodiments, it is understood by those skilled in the art that the invention may be practiced with modifications to the embodiments that are within the scope of the invention as defined by the following claims.

APPENDIX A

0	75	150	225	300	375	450	525	600	675	750	825
1	76	151	226	301	376	451	526	601	676	751	826
2	77	152	227	302	377	452	527	602	677	752	827
3	78	153	228	303	378	453	528	603	678	753	828
4	79	154	229	304	379	454	529	604	679	754	829
5	80	155	230	305	380	455	530	605	680	755	830
6	81	156	231	306	381	456	531	606	681	756	831
7	82	157	232	307	382	457	532	607	682	757	832
8	83	158	233	308	383	458	533	608	683	758	833
9	84	159	234	309	384	459	534	609	684	759	834
10	85	160	235	310	385	460	535	610	685	760	835
11	86	161	236	311	386	461	536	611	686	761	836
12	87	162	237	312	387	462	537	612	687	762	837
13	88	163	238	313	388	463	538	613	688	763	838
14	89	164	239	314	389	464	539	614	689	764	839
15	90	165	240	315	390	465	540	615	690	765	840
16	91	166	241	316	391	466	541	616	691	766	841
17	92	167	242	317	392	467	542	617	692	767	842
18	93	168	243	318	393	468	543	618	693	768	843
19	94	169	244	319	394	469	544	619	694	769	844
20	95	170	245	320	395	470	545	620	695	770	845
21	96	171	246	321	396	471	546	621	696	771	846
22	97	172	247	322	397	472	547	622	697	772	847
23	98	173	248	323	398	473	548	623	698	773	848
24	99	174	249	324	399	474	549	624	699	774	849
25	100	175	250	325	400	475	550	625	700	775	850
26	101	176	251	326	401	476	551	626	701	776	851
27	102	177	252	327	402	477	552	627	702	777	852
28	103	178	253	328	403	478	553	628	703	778	853
29	104	179	254	329	404	479	554	629	704	779	854
30	105	180	255	330	405	480	555	630	705	780	855
31	106	181	256	331	406	481	556	631	706	781	856
32	107	182	257	332	407	482	557	632	707	782	857
33	108	183	258	333	408	483	558	633	708	783	858
34	109	184	259	334	409	484	559	634	709	784	859
35	110	185	260	335	410	485	560	635	710	785	860
36	111	186	261	336	411	486	561	636	711	786	861
37	112	187	262	337	412	487	562	637	712	787	862
38	113	188	263	338	413	488	563	638	713	788	863
39	114	189	264	339	414	489	564	639	714	789	864
40	115	190	265	340	415	490	565	640	715	790	865
41	116	191	266	341	416	491	566	641	716	791	866
42	117	192	267	342	417	492	567	642	717	792	867
43	118	193	268	343	418	493	568	643	718	793	868
44	119	194	269	344	419	494	569	644	719	794	869
45	120	195	270	345	420	495	570	645	720	795	870
46	121	196	271	346	421	496	571	646	721	796	871
47	122	197	272	347	422	497	572	647	722	797	872
48	123	198	273	348	423	498	573	648	723	798	873
49	124	199	274	349	424	499	574	649	724	799	874
50	125	200	275	350	425	500	575	650	725	800	875
51	126	201	276	351	426	501	576	651	726	801	876
52	127	202	277	352	427	502	577	652	727	802	877
53	128	203	278	353	428	503	578	653	728	803	878
54	129	204	279	354	429	504	579	654	729	804	879
55	130	205	280	355	430	505	580	655	730	805	880
56	131	206	281	356	431	506	581	656	731	806	881
57	132	207	282	357	432	507	582	657	732	807	882

-continued

APPENDIX A

58	133	208	283	358	433	508	583	658	733	808	883
59	134	209	284	359	434	509	584	659	734	809	884
60	135	210	285	360	435	510	585	660	735	810	885
61	136	211	286	361	436	511	586	661	736	811	886
62	137	212	287	362	437	512	587	662	737	812	887
63	138	213	288	363	438	513	588	663	738	813	888
64	139	214	289	364	439	514	589	664	739	814	889
65	140	215	290	365	440	515	590	665	740	815	890
66	141	216	291	366	441	516	591	666	741	816	891
67	142	217	292	367	442	517	592	667	742	817	892
68	143	218	293	368	443	518	593	668	743	818	893
69	144	219	294	369	444	519	594	669	744	819	894
70	145	220	295	370	445	520	595	670	745	820	895
71	146	221	296	371	446	521	596	671	746	821	896
72	147	222	297	372	447	522	597	672	747	822	897
73	148	223	298	373	448	523	598	673	748	823	898
74	149	224	299	374	449	524	599	674	749	824	899
900	975	1050	2227	2302	2377	2452	2527	2602	2677	2752	2827
901	976	1051	2228	2303	2378	2453	2528	2603	2678	2753	2828
902	977	1052	2229	2304	2379	2454	2529	2604	2679	2754	2929
903	973	1053	2230	2305	2380	2455	2530	2605	2680	2755	2830
904	979	1054	2231	2306	2381	2456	2531	2606	2681	2756	2831
905	980	1055	2232	2307	2382	2457	2532	2607	2682	2757	2832
906	981	1056	2233	2308	2383	2458	2533	2608	2683	2758	2833
907	982	1057	2234	2309	2384	2459	2534	2609	2684	2759	2834
908	983	1058	2235	2310	2385	2460	2535	2610	2685	2760	2835
909	984	1059	2236	2311	2386	2461	2536	2611	2686	2761	2836
910	985	1060	2237	2312	2387	2462	2537	2612	2687	2762	2837
911	986	1061	2238	2313	2388	2463	2538	2613	2688	2763	2838
912	987	1062	2239	2314	2389	2464	2539	2614	2689	2764	2839
913	988	1063	2240	2315	2390	2465	2540	2615	2690	2765	2840
914	989	1064	2241	2316	2391	2466	2541	2616	2691	2766	2841
915	990	1065	2242	2317	2392	2467	2542	2617	2692	2767	2842
916	991	1066	2243	2318	2393	2468	2543	2618	2693	2768	2843
917	992	1067	2244	2319	2394	2469	2544	2619	2694	2769	2844
918	993	1068	2245	2320	2395	2470	2545	2620	2695	2770	2845
919	994	1069	2246	2321	2396	2471	2546	2621	2696	2771	2846
920	995	1070	2247	2322	2397	2472	2547	2622	2697	2772	2847
921	996	1071	2248	2323	2398	2473	2548	2623	2698	2773	2848
922	997	1072	2249	2324	2399	2474	2549	2624	2699	2774	2849
923	998	1073	2250	2325	2400	2475	2550	2625	2700	2775	2850
924	999	1074	2251	2326	2401	2476	2551	2626	2701	2776	2851
925	1000	1075	2252	2327	2402	2477	2552	2627	2702	2777	2852
926	1001	1076	2253	2328	2403	2478	2553	2628	2703	2778	2853
927	1002	1077	2254	2329	2404	2479	2554	2629	2704	2779	2854
928	1003	1078	2255	2330	2405	2480	2555	2630	2705	2780	2855
929	1004	1079	2256	2331	2406	2481	2556	2631	2706	2781	2856
930	1005	1080	2257	2332	2407	2482	2557	2632	2707	2782	2857
931	1006	1081	2258	2333	2408	2483	2558	2633	2708	2783	2858
932	1007	1082	2259	2334	2409	2484	2559	2634	2709	2784	2859
933	1008	1083	2260	2335	2410	2485	2560	2635	2710	2785	2860
934	1009	1084	2261	2336	2411	2486	2561	2636	2711	2786	2861
935	1010	1085	2262	2337	2412	2487	2562	2637	2712	2787	2862
936	1011	1086	2263	2338	2413	2488	2563	2638	2713	2788	2863
937	1012	1087	2264	2339	2414	2489	2564	2639	2714	2789	2864
938	1013	1088	2265	2340	2415	2490	2565	2640	2715	2790	2865
939	1014	1089	2266	2341	2416	2491	2566	2641	2716	2791	2866
940	1015	1090	2267	2342	2417	2492	2567	2642	2717	2792	2867
941	1016	1091	2268	2343	2418	2493	2568	2643	2718	2793	2868
942	1017	1092	2269	2344	2419	2494	2569	2644	2719	2794	2869
943	1018	1093	2270	2345	2420	2495	2570	2645	2720	2795	2870
944	1019	1094	2271	2346	2421	2496	2571	2646	2721	2796	2871
945	1020	1095	2272	2347	2422	2497	2572	2647	2722	2797	2872
946	1021	1096	2273	2348	2423	2498	2573	2648	2723	2798	2873
947	1022	1097	2274	2349	2424	2499	2574	2649	2724	2799	2874
948	1023	1098	2275	2350	2425	2500	2575	2650	2725	2800	2875
949	1024	1099	2276	2351	2426	2501	2576	2651	2726	2801	2876
950	1025	1100	2277	2352	2427	2502	2577	2652	2727	2802	2877
951	1026	1101	2278	2353	2428	2503	2578	2653	2728	2803	2878
952	1027	2204	2279	2354	2429	2504	2579	2654	2729	2804	2879
953	1028	2205	2280	2355	2430	2505	2580	2655	2730	2805	2880
954	1029	2206	2281	2356	2431	2506	2581	2656	2731	2806	2881
955	1030	2207	2282	2357	2432	2507	2582	2657	2732	2807	2882
956	1031	2208	2283	2358	2433	2508	2583	2658	2733	2808	2883
957	1032	2209	2284	2359	2434	2509	2584	2659	2734	2809	2884
958	1033	2210	2285	2360	2435	2510	2585	2660	2735	2810	2885
959	1034	2211	2286	2361	2436	2511	2586	2661	2736	2811	2886

-continued

APPENDIX A

960	1035	2212	2287	2362	2437	2512	2587	2662	2737	2812	2887
961	1036	2213	2288	2363	2438	2513	2588	2663	2738	2813	2888
962	1037	2214	2289	2364	2439	2514	2589	2664	2739	2814	2889
963	1038	2215	2290	2365	2440	2515	2590	2665	2740	2815	2890
964	1039	2216	2291	2366	2441	2516	2591	2666	2741	2816	2891
965	1040	2217	2292	2367	2442	2517	2592	2667	2742	2817	2892
966	1041	2218	2293	2368	2443	2518	2593	2668	2743	2818	2893
967	1042	2219	2294	2369	2444	2519	2594	2669	2744	2819	2894
968	1043	2220	2295	2370	2445	2520	2595	2670	2745	2820	2895
969	1044	2221	2296	2371	2446	2521	2596	2671	2746	2821	2896
970	1045	2222	2297	2372	2447	2522	2597	2672	2747	2822	2897
971	1046	2223	2298	2373	2448	2523	2598	2673	2748	2823	2898
972	1047	2224	2299	2374	2449	2524	2599	2674	2749	2824	2899
973	1048	2225	2300	2375	2450	2525	2600	2675	2750	2825	2900
974	1049	2226	2301	2376	2451	2526	2601	2676	2751	2826	2901
2902	2977	3052	3127	3202	3277	4454	4529	4604	4679	4754	4829
2903	2978	3053	3128	3203	3278	4455	4530	4605	4680	4755	4830
2904	2979	3054	3129	3204	3279	4456	4531	4606	4681	4756	4831
2905	2980	3055	3130	3205	3280	4457	4532	4607	4682	4757	4832
2906	2981	3056	3131	3206	3281	4458	4533	4608	4683	4758	4833
2907	2982	3057	3132	3207	3282	4459	4534	4609	4684	4759	4834
2908	2983	3058	3133	3208	3283	4460	4535	4610	4685	4760	4835
2909	2984	3059	3134	3209	3284	4461	4536	4611	4686	4761	4836
2910	2985	3060	3135	3210	3285	4462	4537	4612	4687	4762	4837
2911	2986	3061	3136	3211	3286	4463	4538	4613	4688	4763	4838
2912	2987	3062	3137	3212	3287	4464	4539	4614	4689	4764	4839
2913	2988	3063	3138	3213	3288	4465	4540	4615	4690	4765	4840
2914	2989	3064	3139	3214	3289	4466	4541	4616	4691	4766	4841
2915	2990	3065	3140	3215	3290	4467	4542	4617	4692	4767	4842
2916	2991	3066	3141	3216	3291	4468	4543	4618	4693	4768	4843
2917	2992	3067	3142	3217	3292	4469	4544	4619	4694	4769	4844
2918	2993	3068	3143	3218	3293	4470	4545	4620	4695	4770	4845
2919	2994	3069	3144	3219	3294	4471	4546	4621	4696	4771	4846
2920	2995	3070	3145	3220	3295	4472	4547	4622	4697	4772	4847
2921	2996	3071	3146	3221	3296	4473	4548	4623	4698	4773	4848
2922	2997	3072	3147	3222	3297	4474	4549	4624	4699	4774	4849
2923	2998	3073	3148	3223	3298	4475	4550	4625	4700	4775	4850
2924	2999	3074	3149	3224	3299	4476	4551	4626	4701	4776	4851
2925	3000	3075	3150	3225	3300	4477	4552	4627	4702	4777	4852
2926	3001	3076	3151	3226	3301	4478	4553	4628	4703	4778	4853
2927	3002	3077	3152	3227	3302	4479	4554	4629	4704	4779	4854
2928	3003	3078	3153	3228	3303	4480	4555	4630	4705	4780	4855
2929	3004	3079	3154	3229	3304	4481	4556	4631	4706	4781	4856
2930	3005	3080	3155	3230	3305	4482	4557	4632	4707	4782	4857
2931	3006	3081	3156	3231	4408	4483	4558	4633	4708	4783	4858
2932	3007	3082	3157	3232	4409	4484	4559	4634	4709	4784	4859
2933	3008	3083	3158	3233	4410	4485	4560	4635	4710	4785	4860
2934	3009	3084	3159	3234	4411	4486	4561	4636	4711	4786	4861
2935	3010	3085	3160	3235	4412	4487	4562	4637	4712	4787	4862
2936	3011	3086	3161	3236	4413	4488	4563	4638	4713	4788	4863
2937	3012	3087	3162	3237	4414	4489	4564	4639	4714	4789	4864
2938	3013	3088	3163	3238	4415	4490	4565	4640	4715	4790	4865
2939	3014	3089	3164	3239	4416	4491	4566	4641	4716	4791	4866
2940	3015	3090	3165	3240	4417	4492	4567	4642	4717	4792	4867
2941	3016	3091	3166	3241	4418	4493	4568	4643	4718	4793	4868
2942	3017	3092	3167	3242	4419	4494	4569	4644	4719	4794	4869
2943	3018	3093	3168	3243	4420	4495	4570	4645	4720	4795	4870
2944	3019	3094	3169	3244	4421	4496	4571	4646	4721	4796	4871
2945	3020	3095	3170	3245	4422	4497	4572	4647	4722	4797	4872
2946	3021	3096	3171	3246	4423	4498	4573	4648	4723	4798	4873
2947	3022	3097	3172	3247	4424	4499	4574	4649	4724	4799	4874
2948	3023	3098	3173	3248	4425	4500	4575	4650	4725	4800	4875
2949	3024	3099	3174	3249	4426	4501	4576	4651	4726	4801	4876
2950	3025	3100	3175	3250	4427	4502	4577	4652	4727	4802	4877
2951	3026	3101	3176	3251	4428	4503	4578	4653	4728	4803	4878
2952	3027	3102	3177	3252	4429	4504	4579	4654	4729	4804	4879
2953	3028	3103	3178	3253	4430	4505	4580	4655	4730	4805	4880
2954	3029	3104	3179	3254	4431	4506	4581	4656	4731	4806	4881
2955	3030	3105	3180	3255	4432	4507	4582	4657	4732	4807	4882
2956	3031	3106	3181	3256	4433	4508	4583	4658	4733	4808	4883
2957	3032	3107	3182	3257	4434	4509	4584	4659	4734	4809	4884
2958	3033	3108	3183	3258	4435	4510	4585	4660	4735	4810	4885
2959	3034	3109	3184	3259	4436	4511	4586	4661	4736	4811	4886
2960	3035	3110	3185	3260	4437	4512	4587	4662	4737	4812	4887
2961	3036	3111	3186	3261	4438	4513	4588	4663	4738	4813	4888
2962	3037	3112	3187	3262	4439	4514	4589	4664	4739	4814	4889
2963	3038	3113	3188	3263	4440	4515	4590	4665	4740	4815	4890

-continued

APPENDIX A

2964	3039	3114	3189	3264	4441	4516	4591	4666	4741	4816	4891
2965	3040	3115	3190	3265	4442	4517	4592	4667	4742	4817	4892
2966	3041	3116	3191	3266	4443	4518	4593	4678	4743	4818	4893
2967	3042	3117	3192	3267	4444	4519	4594	4679	4744	4819	4894
2968	3043	3118	3193	3268	4445	4520	4595	4680	4745	4820	4895
2969	3044	3119	3194	3269	4446	4521	4596	4681	4746	4821	4896
2970	3045	3120	3195	3270	4447	4522	4597	4682	4747	4822	4897
2971	3046	3121	3196	3271	4448	4523	4598	4683	4748	4823	4898
2972	3047	3122	3197	3272	4449	4524	4599	4684	4749	4824	4899
2973	3048	3123	3198	3273	4450	4525	4600	4685	4750	4825	4900
2974	3049	3124	3199	3274	4451	4526	4601	4686	4751	4826	4901
2975	3050	3125	3200	3275	4452	4527	4602	4687	4752	4827	4902
2976	3051	3126	3201	3276	4453	4528	4603	4688	4753	4828	4903

4904	4979	5054	5129	5204	5279	5354	5429	5504	6681	6756	6831
4905	4980	5055	5130	5205	5280	5355	5430	5505	6682	6757	6832
4906	4981	5056	5131	5206	5281	5356	5431	5506	6683	6758	6833
4907	4982	5057	5132	5207	5282	5357	5432	5507	6684	6759	6834
4908	4983	5058	5133	5208	5283	5358	5433	5508	6685	6760	6835
4909	4984	5059	5134	5209	5284	5359	5434	5509	6686	6761	6836
4910	4985	5060	5135	5210	5285	5360	5435	6612	6687	6762	6837
4911	4986	5061	5136	5211	5286	5361	5436	6613	6688	6763	6838
4912	4987	5062	5137	5212	5287	5362	5437	6614	6689	6764	6839
4913	4988	5063	5138	5213	5288	5363	5438	6615	6690	6765	6840
4914	4989	5064	5139	5214	5289	5364	5439	6616	6691	6766	6841
4915	4990	5065	5140	5215	5290	5365	5440	6617	6692	6767	6842
4916	4991	5066	5141	5216	5291	5366	5441	6618	6693	6768	6843
4917	4992	5067	5142	5217	5292	5367	5442	6619	6692	6769	6844
4918	4993	5068	5143	5218	5293	5368	5443	6620	6693	6770	6845
4919	4994	5069	5144	5219	5294	5369	5444	6621	6694	6771	6846
4920	4995	5070	5145	5220	5295	5370	5445	6622	6695	6772	6847
4921	4996	5071	5146	5221	5296	5371	5446	6623	6696	6773	6848
4922	4997	5072	5147	5222	5297	5372	5447	6624	6697	6774	6849
4923	4998	5073	5148	5223	5298	5373	5448	6625	6698	6775	6850
4924	4999	5074	5149	5224	5299	5374	5449	6626	6699	6776	6851
4925	5000	5075	5150	5225	5300	5375	5450	6627	6700	6777	6852
4926	5001	5076	5151	5226	5301	5376	5451	6628	6701	6778	6853
4927	5002	5077	5152	5227	5302	5377	5452	6629	6702	6779	6854
4928	5003	5078	5153	5228	5303	5378	5453	6630	6703	6780	6855
4929	5004	5079	5154	5229	5304	5379	5454	6631	6702	6781	6856
4930	5005	5080	5155	5230	5305	5380	5455	6632	6703	6782	6857
4931	5006	5081	5156	5231	5306	5381	5456	6633	6704	6783	6858
4932	5007	5082	5157	5232	5307	5382	5457	6634	6705	6784	6859
4933	5008	5083	5158	5233	5308	5383	5458	6635	6706	6785	6860
4934	5009	5084	5159	5234	5309	5384	5459	6636	6707	6786	6861
4935	5010	5085	5160	5235	5310	5385	5460	6637	6708	6787	6862
4936	5011	5086	5161	5236	5311	5386	5461	6638	6709	6788	6863
4937	5012	5087	5162	5237	5312	5387	5462	6639	6710	6789	6864
4938	5013	5088	5163	5238	5313	5388	5463	6640	6711	6790	6865
4939	5014	5089	5164	5239	5314	5389	5464	6641	6712	6791	6866
4940	5015	5090	5165	5240	5315	5390	5465	6642	6713	6792	6867
4941	5016	5091	5166	5241	5316	5391	5466	6643	6712	6793	6868
4942	5017	5092	5167	5242	5317	5392	5467	6644	6713	6794	6869
4943	5018	5093	5168	5243	5318	5393	5468	6645	6714	6795	6870
4944	5019	5094	5169	5244	5319	5394	5469	6646	6715	6796	6871
4945	5020	5095	5170	5245	5320	5395	5470	6647	6716	6797	6872
4946	5021	5096	5171	5246	5321	5396	5471	6648	6717	6798	6873
4947	5022	5097	5172	5247	5322	5397	5472	6649	6718	6799	6874
4948	5023	5098	5173	5248	5323	5398	5473	6650	6719	6800	6875
4949	5024	5099	5174	5249	5324	5399	5474	6651	6720	6801	6876
4950	5025	5100	5175	5250	5325	5400	5475	6652	6721	6802	6877
4951	5026	5101	5176	5251	5326	5401	5476	6653	6722	6803	6878
4952	5027	5102	5177	5252	5327	5402	5477	6654	6723	6804	6879
4953	5028	5103	5178	5253	5328	5403	5478	6655	6722	6805	6880
4954	5029	5104	5179	5254	5329	5404	5479	6656	6723	6806	6881
4955	5030	5105	5180	5255	5330	5405	5480	6657	6724	6807	6882
4956	5031	5106	5181	5256	5331	5406	5481	6658	6725	6808	6883
4957	5032	5107	5182	5257	5332	5407	5482	6659	6726	6809	6884
4958	5033	5108	5183	5258	5333	5408	5483	6660	6727	6810	6885
4959	5034	5109	5184	5259	5334	5409	5484	6661	6728	6811	6886
4960	5035	5110	5185	5260	5335	5410	5485	6662	6729	6812	6887
4961	5036	5111	5186	5261	5336	5411	5486	6663	6730	6813	6888
4962	5037	5112	5187	5262	5337	5412	5487	6664	6731	6814	6889
4963	5038	5113	5188	5263	5338	5413	5488	6665	6732	6815	6890
4964	5039	5114	5189	5264	5339	5414	5489	6666	6733	6816	6891
4965	5040	5115	5190	5265	5340	5415	5490	6667	6732	6817	6892
4966	5041	5116	5191	5266	5341	5416	5491	6668	6733	6818	6893
4967	5042	5117	5192	5267	5342	5417	5492	6669	6734	6819	6894

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APPENDIX A

4968	5043	5118	5193	5268	5343	5418	5493	6670	6735	6820	6895
4969	5044	5119	5194	5269	5344	5419	5494	6671	6736	6821	6896
4970	5045	5120	5195	5270	5345	5420	5495	6672	6737	6822	6897
4971	5046	5121	5196	5271	5346	5421	5496	6673	6738	6823	6898
4972	5047	5122	5197	5272	5347	5422	5497	6674	6739	6824	6899
4973	5048	5123	5198	5273	5348	5423	5498	6675	6740	6825	6900
4974	5049	5124	5199	5274	5349	5424	5499	6676	6741	6826	6901
4975	5050	5125	5200	5275	5350	5425	5500	6677	6742	6827	6902
4976	5051	5126	5201	5276	5351	5426	5501	6678	6743	6828	6903
4977	5052	5127	5202	5277	5352	5427	5502	6679	6742	6829	6904
4978	5053	5128	5203	5278	5353	5428	5503	6680	6743	6830	6905
6906	6930	6954	6978	7002	7026	7050	7074	7098	7122	7146	7170
6907	6931	6955	6979	7003	7027	7051	7075	7099	7123	7147	7171
6908	6932	6956	6980	7004	7028	7052	7076	7100	7124	7148	7172
6909	6933	6957	6981	7005	7029	7053	7077	7101	7125	7149	7173
6910	6934	6958	6982	7006	7030	7054	7078	7102	7126	7150	7174
6911	6935	6959	6983	7007	7031	7055	7079	7103	7127	7151	7175
6912	6936	6960	6984	7008	7032	7056	7080	7104	7128	7152	7176
6913	6937	6961	6985	7009	7033	7057	7081	7105	7129	7153	7177
6914	6938	6962	6986	7010	7034	7058	7082	7106	7130	7154	7178
6915	6939	6963	6987	7011	7035	7059	7083	7107	7131	7155	7179
6916	6940	6964	6988	7012	7036	7060	7084	7108	7132	7156	7180
6917	6941	6965	6989	7013	7037	7061	7085	7109	7133	7157	7181
6918	6942	6966	6990	7014	7038	7062	7086	7110	7134	7158	7182
6919	6943	6967	6991	7015	7039	7063	7087	7111	7133	7159	7183
6920	6944	6968	6992	7016	7040	7064	7088	7112	7134	7160	7184
6921	6945	6969	6993	7017	7041	7065	7089	7113	7135	7161	
6922	6946	6970	6994	7018	7042	7066	7090	7114	7136	7162	
6923	6947	6971	6995	7019	7043	7067	7091	7115	7137	7163	
6924	6948	6972	6996	7020	7044	7068	7092	7116	7138	7164	
6925	6949	6973	6997	7021	7045	7069	7093	7117	7139	7165	
6926	6950	6974	6998	7022	7046	7070	7094	7118	7140	7166	
6927	6951	6975	6999	7023	7047	7071	7095	7119	7141	7167	
6928	6952	6976	7000	7024	7048	7072	7096	7120	7142	7168	
6929	6953	6977	7001	7025	7049	7073	7097	7121	7143	7169	

The invention claimed is:

1. A multiple access, spread-spectrum communication system for processing a plurality of telecommunication information signals received simultaneously for simultaneous transmission over a radio frequency (RF) channel as a code-division-multiplexed (CDM) signal, the system comprising:

means for receiving a call request signal corresponding to a telecommunication line information signal, and a user identification signal identifying a user to which the call request and information signal are addressed;

a plurality of modem processing means, one of the plurality of modem processing means providing a global pilot code signal, and each of the modem processing means providing a respective message code signal and combining one of the plurality of information signals with the respective message code signal to provide a spread-spectrum processed message signal, the plurality of message code signals of the plurality of modem processing means being synchronized to the global pilot code signal;

assignment means responsive to a channel assignment signal for coupling the information signals received on the telecommunication lines to respective indicated ones of the plurality of modem means;

a system channel controller, coupled to a remote call-processing means and responsive to the user identification signal, for providing the channel assignment signal; and

an RF transmitter means, connected to each of the plurality of modem processing means, for combining the plurality of spread-spectrum processed message signals with the global pilot code signal to generate a CDM signal; for modulating a carrier signal with the CDM signal and for transmitting the modulated carrier signal through an RF communication channel.

2. The multiple-access spread-spectrum communication system of claim 1, wherein one of the plurality of modem processing means further comprises:

a) code generation means comprising a generic pilot code means providing a pilot code signal, and a message means for generating a plurality of message code signals; and

b) spreading means coupled to the message means for combining each of the information signals, user identification signals, and call type signals with a respective one of the plurality of message code signals to generate a plurality of spread-spectrum processed message signals.

3. The multiple access spread-spectrum-communication system of claim 2, wherein:

the generic pilot code means provides the global pilot code signal, and the message means is responsive to a timing signal which is synchronous with the global pilot code signal, such that each of the plurality of message code signals of the plurality of modem processing means is synchronous with the global pilot code signal.

4. The multiple access spread-spectrum communication system of claim 1, wherein:

each of the plurality of information signals has several different channel rates; and

each of the plurality of message code signals supports a pre-determined information channel rate;

and the system further comprises:

remote call-processing means for providing a call type signal corresponding to the information signal rate for each of the information signals; and information channel mode modification means, connected to the system channel controller and to the plurality of modem means and responsive to the call type signal, for changing the combination of the information signals and the respective message code signal to another pre-determined one of the message code signals to support a different information channel rate for the message signal.

5. A subscriber unit for a multiple access, spread-spectrum communication system that receives and processes a code-division multiplexed (CDM) signal which modulates a carrier signal in a radio frequency (RF) channel to reconstruct a transmitted information signal assigned to a subscriber comprising:

receiving means for receiving the modulated carrier signal from the RF channel and for demodulating the CDM signal from the carrier signal;

a subscriber unit controller;

modem processing means comprising:

a) global pilot code acquisition means comprising a global pilot code generation means for providing a global pilot code signal; a plurality of global pilot code-phase delayed correlation means for correlating the global pilot code signal with the CDM signal to produce a despread global pilot code signal, the code phase of the global pilot signal being changed responsive to an acquisition signal; and means for determining whether the despread global pilot signal is present to produce an acquisition signal;

b) a plurality of message code generators which produce a plurality of message code signals synchronized to the global pilot code signal; and

c) global pilot code tracking means for producing an error signal responsive to the acquisition signal;

d) means for adjusting the global pilot code signal in phase, responsive to the error signal in a sense to produce the acquisition signal which corresponds to an increased level of the despread global pilot signal; and

e) a plurality of message signal acquisition means for providing a plurality of despread receive message signals, each acquisition means including a plurality of message signal correlators, each message signal correlator correlating a respective one of the message code signals with the CDM signal to produce a respective despread receive message signal.

6. The subscriber unit of claim 5, wherein:

the signal from the radio frequency (RF) channel includes a user identification signal and the call type signal each associated with the information signal and assigned to a subscriber unit.

7. The subscriber unit of claim 6, wherein:

the despread message signals include the user identification signal and the call type signal; and

the subscriber controller is responsive to the user identification signal to provide the call type signal for the received information signal and the despread information signal to the local subscriber.

8. The subscriber unit of claim 5, wherein:

one of the despread receive message signals includes an information signal and a message type signal corresponding to the information signal rate of one of the information signals; and the subscriber unit further comprises:

information channel mode modification means responsive to the message type signal received with the despread receive message signal for changing a received information signal from a first message code to a second pre-determined message code which second message code supports a different despread information channel rate than the first message code; and

signal conversion means responsive to the message type signal for selectively converting the despread information signal into a sampled data digital signal.

9. A multiple access, spread-spectrum communication system according to claim 1, wherein the global pilot code signal and each message code signal are generated from, and related by, at least one of a family of code generation seeds.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,799,010 Page 1 of 4

DATED : August 25, 1998

INVENTOR(S) : Lomp et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below: On the title page:

On page 2, under other publications, please insert --Raymond W. Nettleton, "Spectral Efficiency in Cellular Land-Mobile Communications: A Spread-Spectrum Approach", UMI Dissertation Information Service (1978) 204 pp.

Hossein Al Avi, "Power Control and Interference Management in a Spread-Spectrum Cellular Mobile Radio System," UMI Dissertation Information Services, (1984). 129 pp.--

At column 6, line 65, delete "AC" and insert therefor --APC--.

At column 7, line 7, delete "AC" and insert therefor --APC--.

At column 9, line 26, delete "AID" and insert therefor --A/D--.

At column 10, line 38, delete "SHC" and insert therefor --SLIC--.

At column 11, line 18, after "these" delete "to".

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,799,010

DATED : August 25, 1998

Page 2 of 4

INVENTOR(S) : Lomp et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

At column 12, line 15 delete "AC" and insert therefor --APC--.

At column 12, line 17 delete "AC" and insert therefor --APC--.

At column 12, line 22 delete "AC" and insert therefor --APC--.

At column 15, line 6 delete "AC" and insert therefor --APC--.

At column 15, line 25 delete "AC" and insert therefor --APC--.

At column 16, line 18 delete "AC" each (each occurrence) and insert therefor --APC--.

At column 16, line 21 delete "AC" and insert therefor --APC--.

At column 47, line 31 delete "tip" and insert therefor --up--.

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,799,010

DATED : August 25, 1998

INVENTOR(S) : Lomp et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

At column 61, line 40 delete "AC" and insert therefor --APC--.

At column 50, line 37 delete "$C_{m\&k}{}^{*}$" and insert therefor --$C^{*}{}_{m\&k}$--.

At column 77 and 78, within subcolumn 10, delete the series of numbers starting with the second instance of "6692" and ending with the "6743" and insert therefor a series of numbers starting with 6694 and ending with 6755 in increments of one.

increments of one.

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,799,010

DATED : August 25, 1998

INVENTOR(S) : Lomp et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

At column 80, within subcolumn 10 delete the series of numbers starting with the second instance of "7133" and ending with "7143" and insert therefor a series of numbers starting with 7135 and ending with 7145 in increments of one.

Signed and Sealed this

Twenty-second Day of February, 2000

Attest:

Q. TODD DICKINSON

Attesting Officer

Commissioner of Patents and Trademarks

EXHIBIT 11

US005614914A

United States Patent [19]

Bolgiano et al.

[11] **Patent Number: 5,614,914**

[45] **Date of Patent: Mar. 25, 1997**

[54] **WIRELESS TELEPHONE DISTRIBUTION SYSTEM WITH TIME AND SPACE DIVERSITY TRANSMISSION FOR DETERMINING RECEIVER LOCATION**

[75] Inventors: **D. Ridgely Bolgiano**, Gladwyne, Pa.; **Gilbert E. LaVean**, Reston, Va.

[73] Assignee: **Interdigital Technology Corporation**, Wilmington, Del.

[21] Appl. No.: **301,230**

[22] Filed: **Sep. 6, 1994**

[51] **Int. Cl.**[6] **G01S 3/02**

[52] **U.S. Cl.** **342/364**; 342/457

[58] **Field of Search** 342/463, 464, 342/386, 417, 457

[56] **References Cited**

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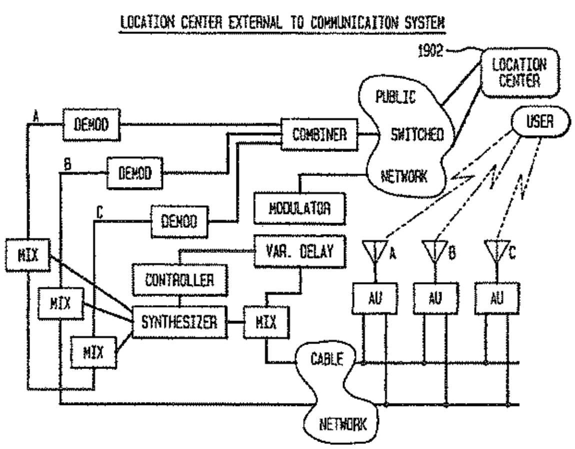
Primary Examiner—Theodore M. Blum

[57] **ABSTRACT**

A wireless communication system combines time and space diversity to reduce fading and simplify receiver design. In particular, a data packet which carries digital telephone traffic, is transmitted at three different times from three different antennas. The mobile subscriber receiver thus receives the same data packet at three different times from three different antennas, and uses the best data packet or combination of the data packets to reduce the effects of fading. A transfer station receives a time division multiplex multiple access (TDMA) signal from a base station carrying telephone data packet traffic to form three data packet repeats at spatially diverse antennas locations. The transfer station further modulates a code division multiple access (CDMA) system using a TDMA signal which links the mobile subscriber receiver to the transfer station. Each data packet received at the transfer station is thus retransmitted at three different times to the mobile subscriber station on a CDMA link. In one embodiment, each transfer station includes the three space diversity antennas. In a second embodiment, three transfer stations, each with one spatially diverse antenna is used. The time division and code division multiplex signals transmitted from space diversity antennas provide the ability to determine subscriber location using the same communication signals which are used for the primary telephone data communication. Specifically, the subscriber station receiver uses the absolute and relative time of arrival of the three repeated data packets to determine the respective distances of the mobile subscriber station to the three transmitting antennas. Since the transmitting antennas are at known fixed locations, receiver location is determined.

80 Claims, 19 Drawing Sheets



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5,365,516	11/1994	Jandrell	370/18

FIG. 1

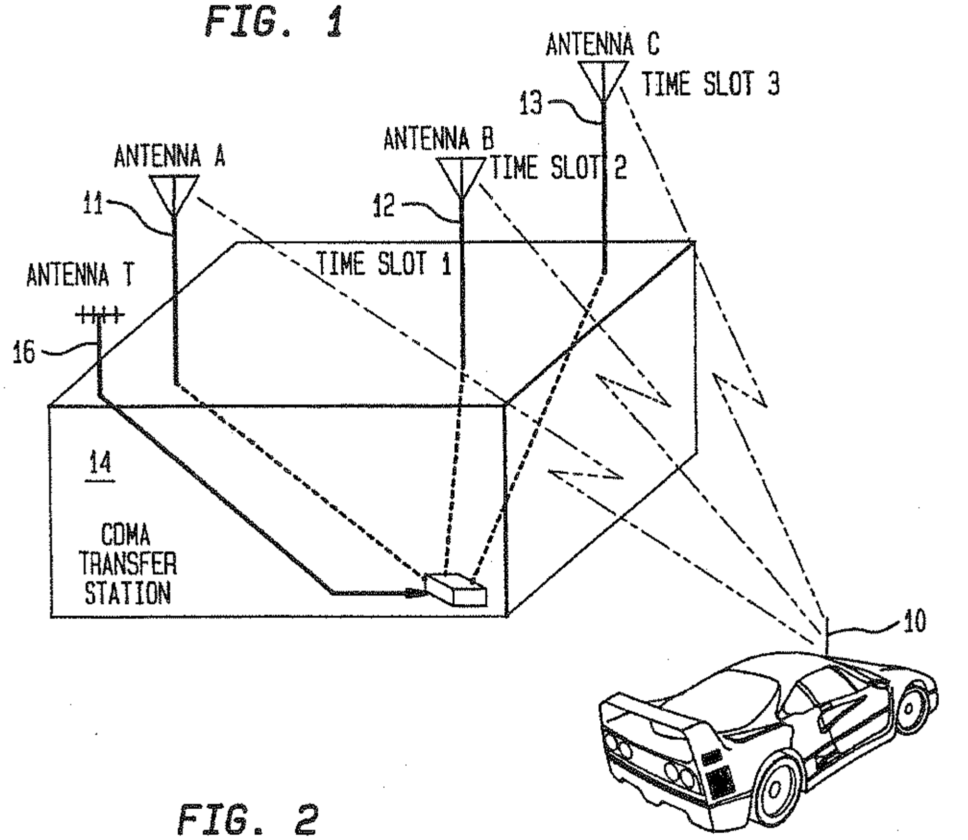

ANTENNA C
TIME SLOT 3
13
ANTENNA B
TIME SLOT 2
12
ANTENNA A
11
TIME SLOT 1
ANTENNA T
16
14
CDMA
TRANSFER
STATION
10

FIG. 2

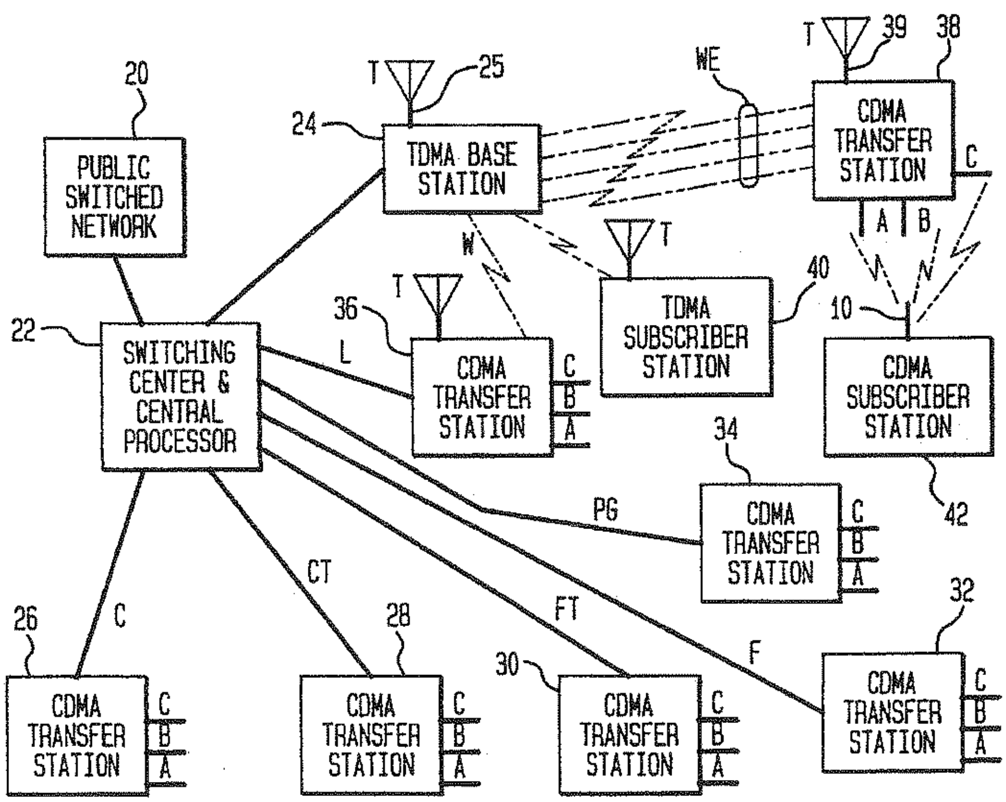
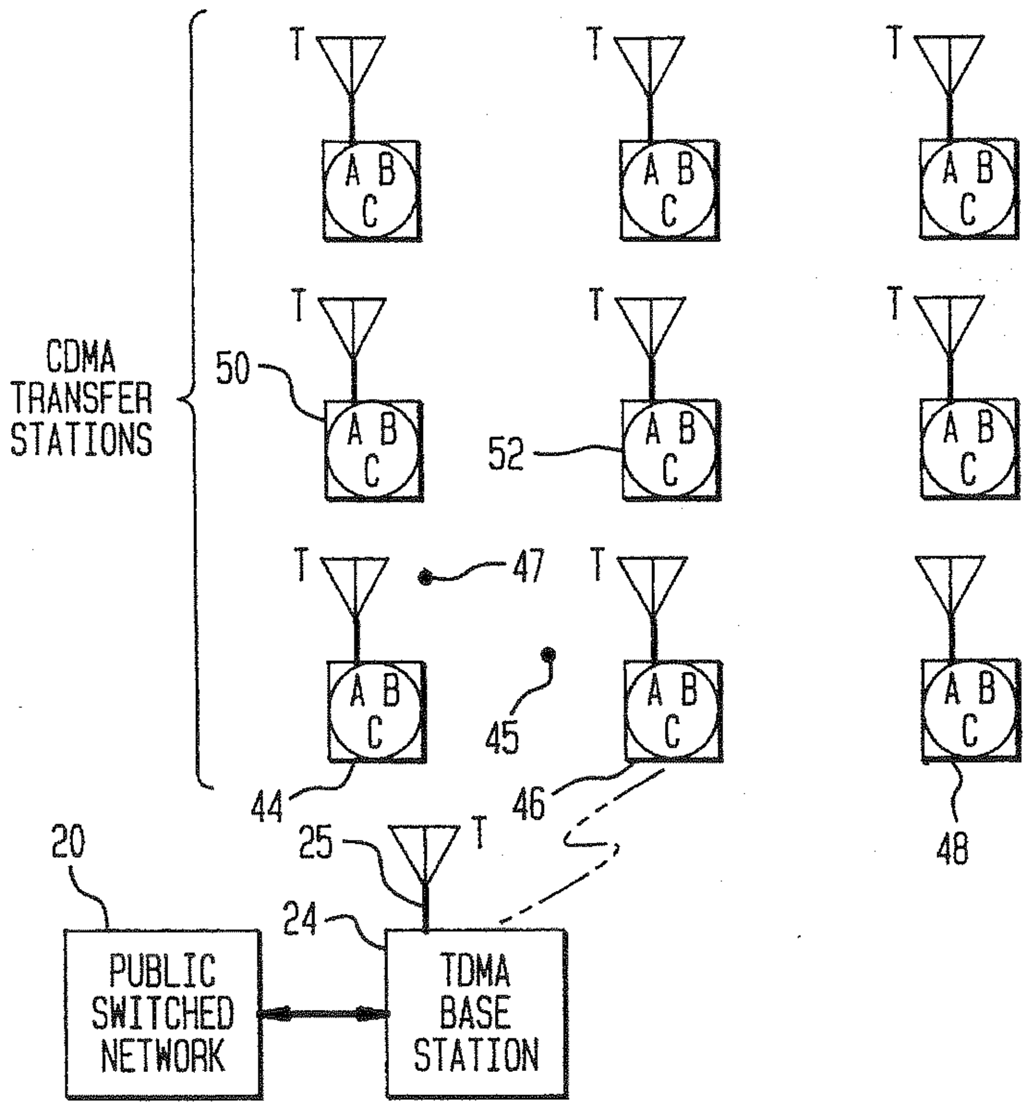

20
PUBLIC
SWITCHED
NETWORK
T
25
24
TDMA BASE
STATION
WE
T
39
38
CDMA
TRANSFER
STATION
C
A
B
W
T
TDMA
SUBSCRIBER
STATION
40
10
22
SWITCHING
CENTER &
CENTRAL
PROCESSOR
36
T
L
CDMA
TRANSFER
STATION
C
B
A
CDMA
SUBSCRIBER
STATION
34
42
PG
CDMA
TRANSFER
STATION
CT
FT
F
26
C
28
30
32
CDMA
TRANSFER
STATION

FIG. 3



CDMA TRANSFER STATIONS
T
A B C
50
52
47
45
44
46
48
20
25
24
PUBLIC SWITCHED NETWORK
TDMA BASE STATION

FIG. 4

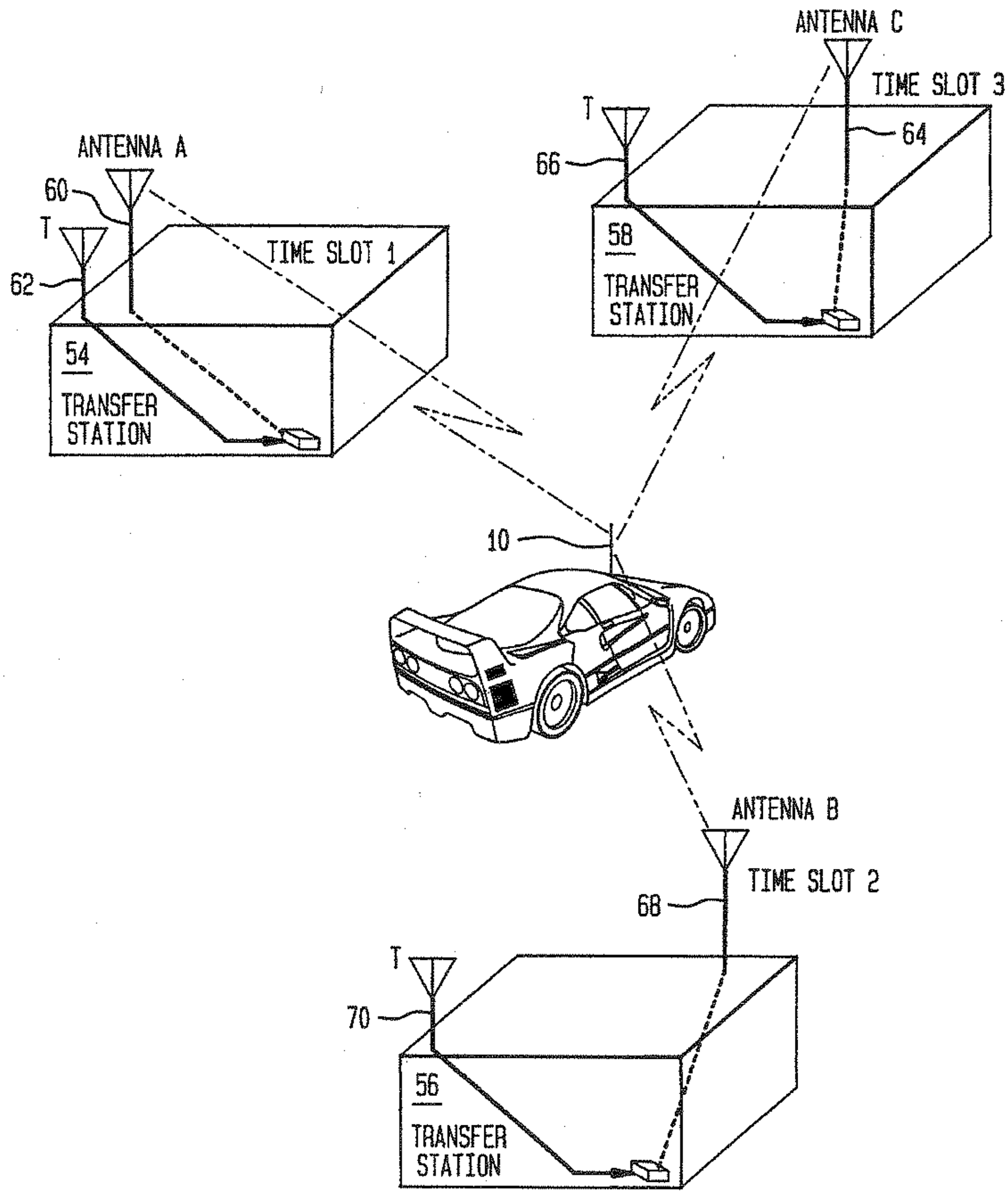

ANTENNA C
TIME SLOT 3
T
64
66
58
TRANSFER
STATION
ANTENNA A
60
T
62
TIME SLOT 1
54
TRANSFER
STATION
10
ANTENNA B
TIME SLOT 2
68
T
70
56
TRANSFER
STATION

FIG. 5

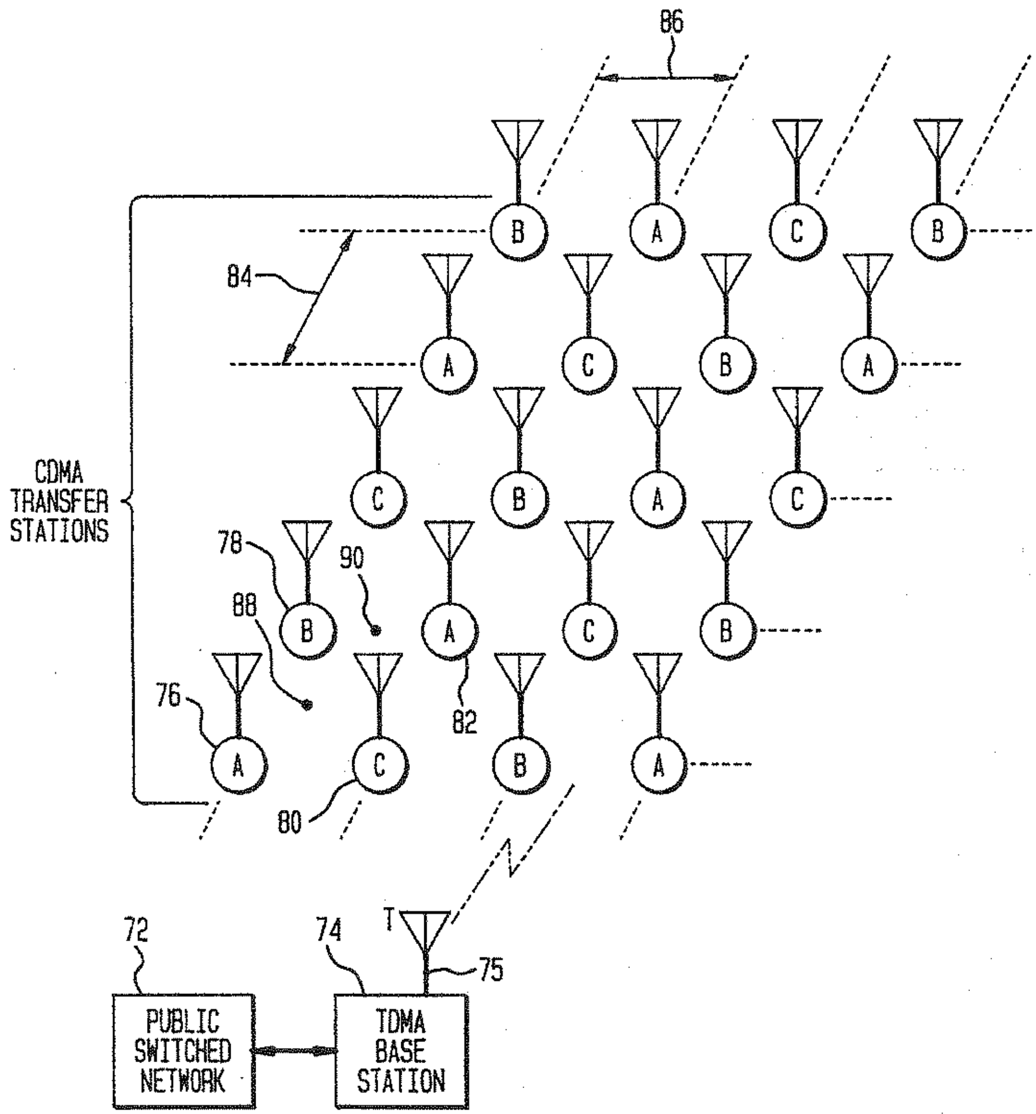

86
84
CDMA
TRANSFER
STATIONS
B
A
C
78
90
88
76
82
80
72
74
T
75
PUBLIC
SWITCHED
NETWORK
TDMA
BASE
STATION

FIG. 6

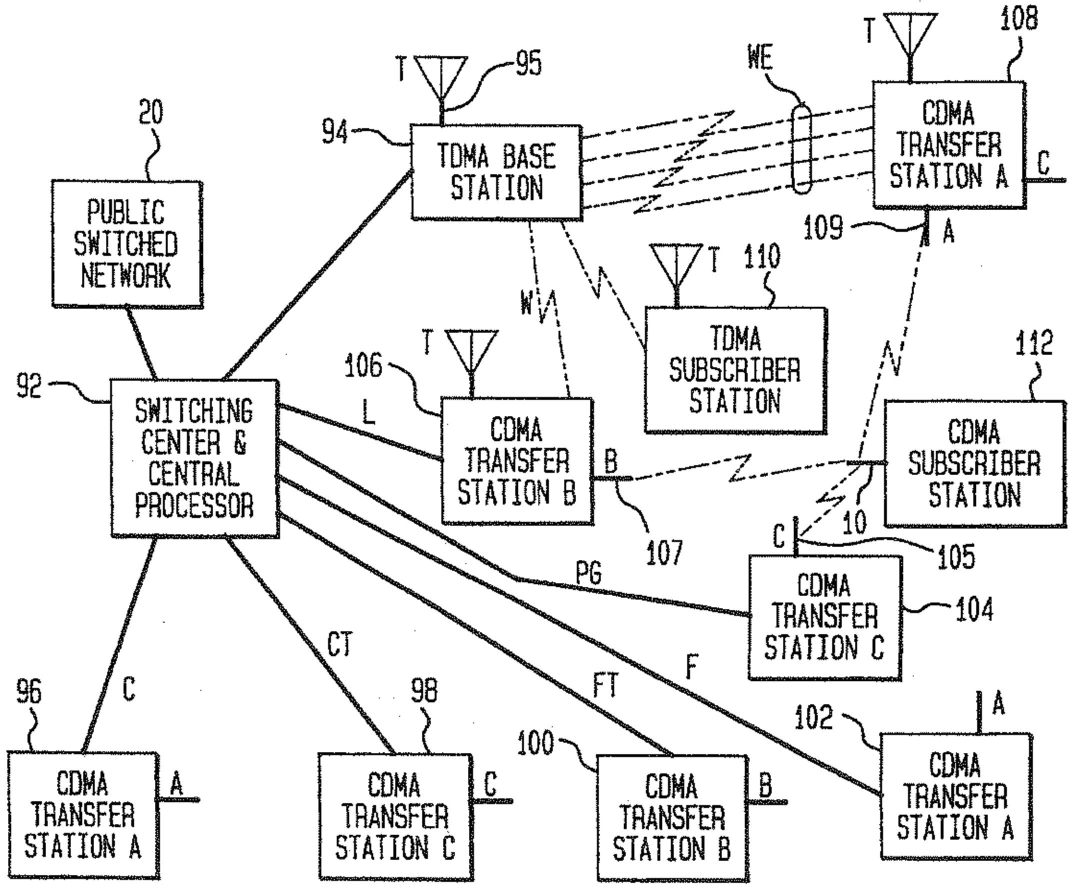


FIG. 7

TIME SLOTS	1	2	3	4	5	6
	RECEIVE	RECEIVE	TRANSMIT	RECEIVE	SCAN	SPARE

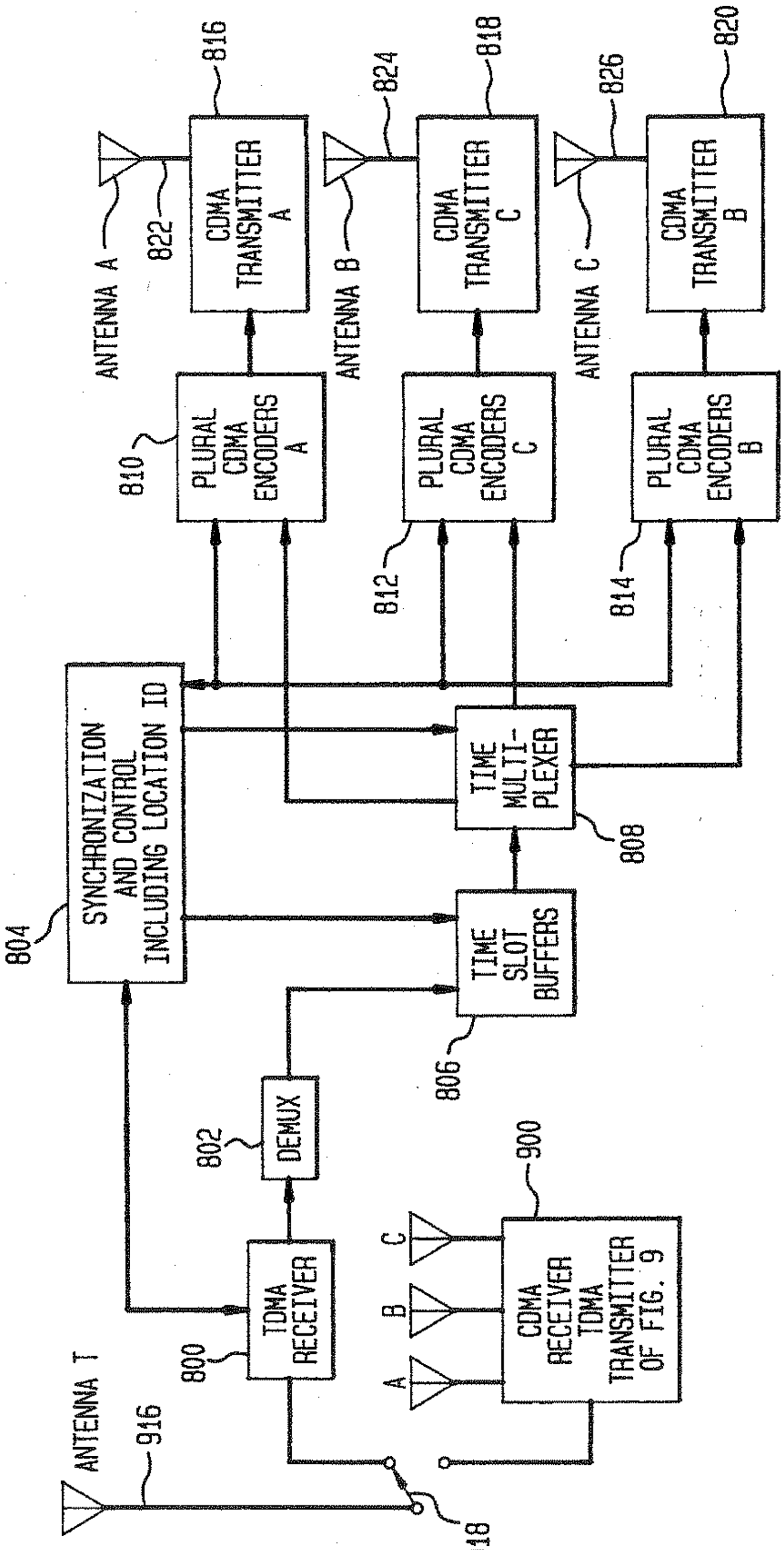


FIG. 8

TRANSFER STATION FORWARD CHANNEL

FIG. 9

TRANSFER STATION REVERSE CHANNEL

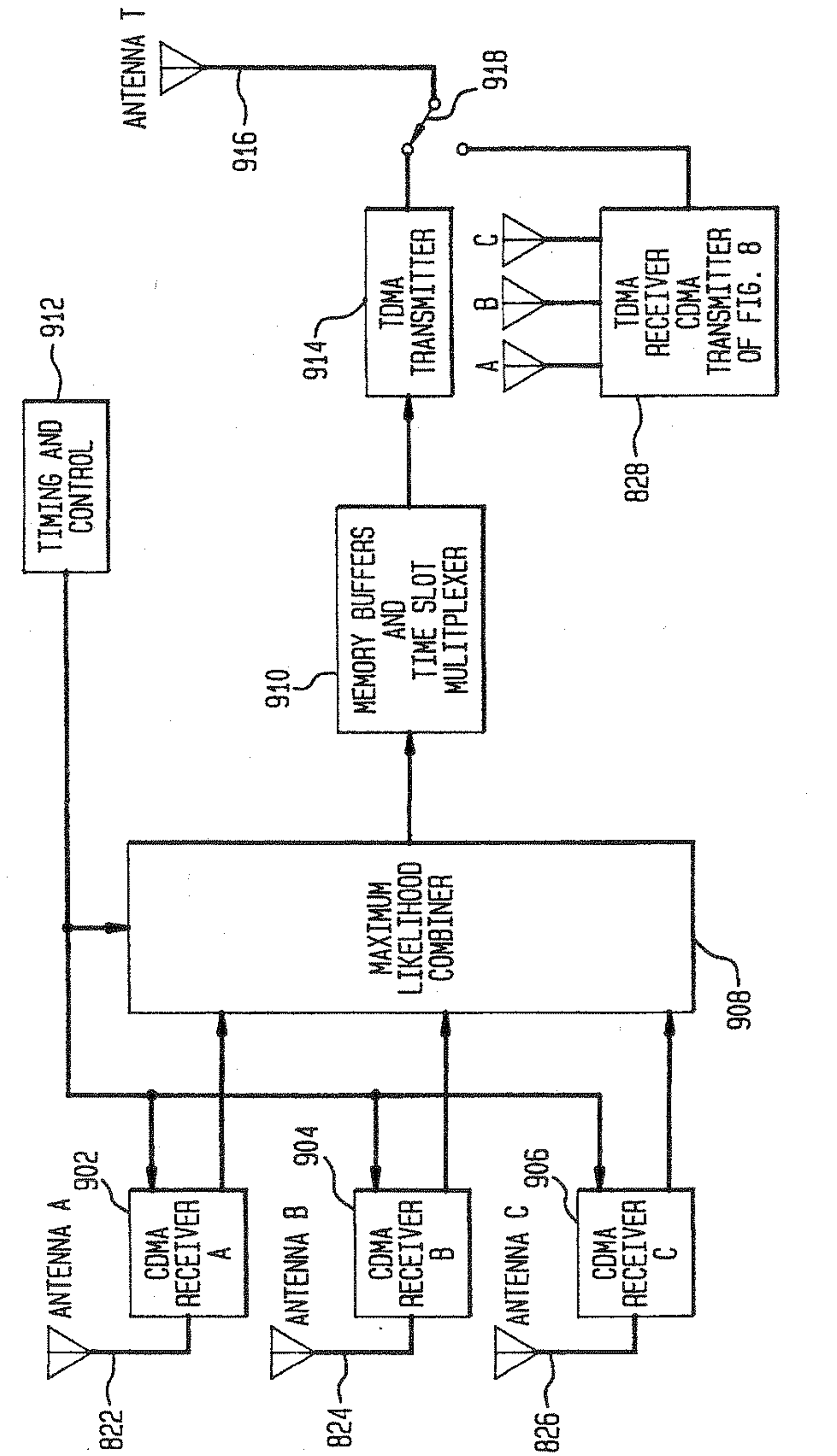


FIG. 10A

TRANSFER STATION CDMA OUTPUT TO ANTENNAS (FORWARD CHANNEL)

TIME SLOTS	1	2	3	4	5	6	1	2
ANTENNA A	T_1	T_2	T_3	T_4	T_5	T_6	T_1	T_2
ANTENNA B	T_6	T_1	T_2	T_3	T_4	T_5	T_6	T_1
ANTENNA C	T_4	T_5	T_6	T_1	T_2	T_3	T_4	T_5

1002

TRANSFER STATION CDMA INPUT FROM ANTENNAS (REVERSE CHANNEL)

TIME SLOTS	1	2	3	4	5	6	1	2
ANTENNA A	R_5	R_6	R_1	R_2	R_3	R_4	R_5	R_6
ANTENNA B	R_5	R_6	R_1	R_2	R_3	R_4	R_5	R_6
ANTENNA C	R_5	R_6	R_1	R_2	R_3	R_4	R_5	R_6

1004

T_X = TRANSMITTER CHANNEL X R_X = RECEIVER CHANNEL X

FIG. 10B

TRANSFER STATION CDMA OUTPUT TO ANTENNAS (FORWARD CHANNEL)

TIME SLOTS	1	2	3	4	5	6	1	2
ANTENNA A	$T_{1,7}$	$T_{2,8}$	$T_{3,9}$	$T_{4,10}$	$T_{5,11}$	$T_{6,12}$	$T_{1,7}$	$T_{2,8}$
ANTENNA B	$T_{6,12}$	$T_{1,7}$	$T_{2,8}$	$T_{3,9}$	$T_{4,10}$	$T_{5,11}$	$T_{6,12}$	$T_{1,7}$
ANTENNA C	$T_{4,10}$	$T_{5,11}$	$T_{6,12}$	$T_{1,7}$	$T_{2,8}$	$T_{3,9}$	$T_{4,10}$	$T_{5,11}$

1006

TRANSFER STATION CDMA INPUT FROM ANTENNAS (REVERSE CHANNEL)

TIME SLOTS	1	2	3	4	5	6	1	2
ANTENNA A	$R_{5,11}$	$R_{6,12}$	$R_{1,7}$	$R_{2,8}$	$R_{3,9}$	$R_{4,10}$	$R_{5,11}$	$R_{6,12}$
ANTENNA B	$R_{5,11}$	$R_{6,12}$	$R_{1,7}$	$R_{2,8}$	$R_{3,9}$	$R_{4,10}$	$R_{5,11}$	$R_{6,12}$
ANTENNA C	$R_{5,11}$	$R_{6,12}$	$R_{1,7}$	$R_{2,8}$	$R_{3,9}$	$R_{4,10}$	$R_{5,11}$	$R_{6,12}$

1008

T_X = TRANSMITTER CHANNEL X R_X = RECEIVER CHANNEL X

$T_{X,Y}$ = TRANSMITTER CHANNELS X AND Y $R_{X,Y}$ = RECEIVER CHANNELS X AND Y

FIG. 11A

TRANSFER STATION CDMA OUTPUT TO ANTENNAS (FORWARD CHANNEL)

TIME SLOTS

ANTENNA A — 1102

1	2	3	4	5	6	1	2
T_1	T_2	T_3	T_4	T_5	T_6	T_1	T_2
T_7	T_8	T_9	T_{10}	T_{11}	T_{12}	T_7	T_8
T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{13}	T_{14}
T_{19}	T_{20}	T_{21}	T_{22}	T_{23}	T_{24}	T_{19}	T_{20}

TIME SLOTS

ANTENNA B — 1104

1	2	3	4	5	6	1	2
T_6	T_1	T_2	T_3	T_4	T_5	T_6	T_1
T_{12}	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}	T_7
T_{18}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{13}
T_{24}	T_{19}	T_{20}	T_{21}	T_{22}	T_{23}	T_{24}	T_{19}

TIME SLOTS

ANTENNA C — 1106

1	2	3	4	5	6	1	2
T_4	T_5	T_6	T_1	T_2	T_3	T_4	T_5
T_{10}	T_{11}	T_{12}	T_7	T_8	T_9	T_{10}	T_{11}
T_{16}	T_{17}	T_{18}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}
T_{22}	T_{23}	T_{24}	T_{19}	T_{20}	T_{21}	T_{22}	T_{23}

FIG. 11B

TRANSFER STATION CDMA INPUT FROM ANTENNAS (REVERSE CHANNEL)

ANTENNA A, ANTENNA B AND ANTENNA C HAVE IDENTICAL TIME SLOTTING — 1108

1	2	3	4	5	6	1	2
R_5	R_6	R_1	R_2	R_3	R_4	R_5	R_6
R_{11}	R_{12}	R_7	R_8	R_9	R_{10}	R_{11}	R_{12}
R_{17}	R_{18}	R_{13}	R_{14}	R_{15}	R_{16}	R_{17}	R_{18}
R_{23}	R_{24}	R_{19}	R_{20}	R_{21}	R_{22}	R_{23}	R_{24}

FIG. 12

TRANSFER STATION

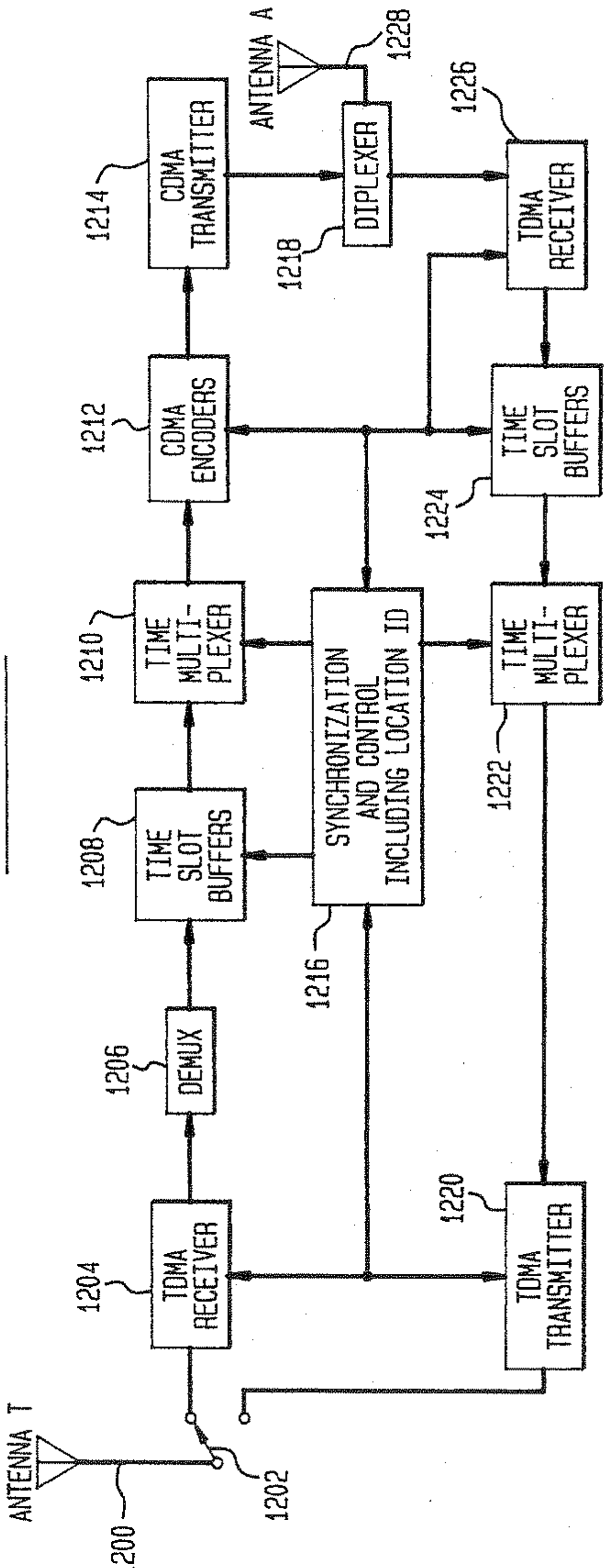


FIG. 13

SUBSCRIBER STATION

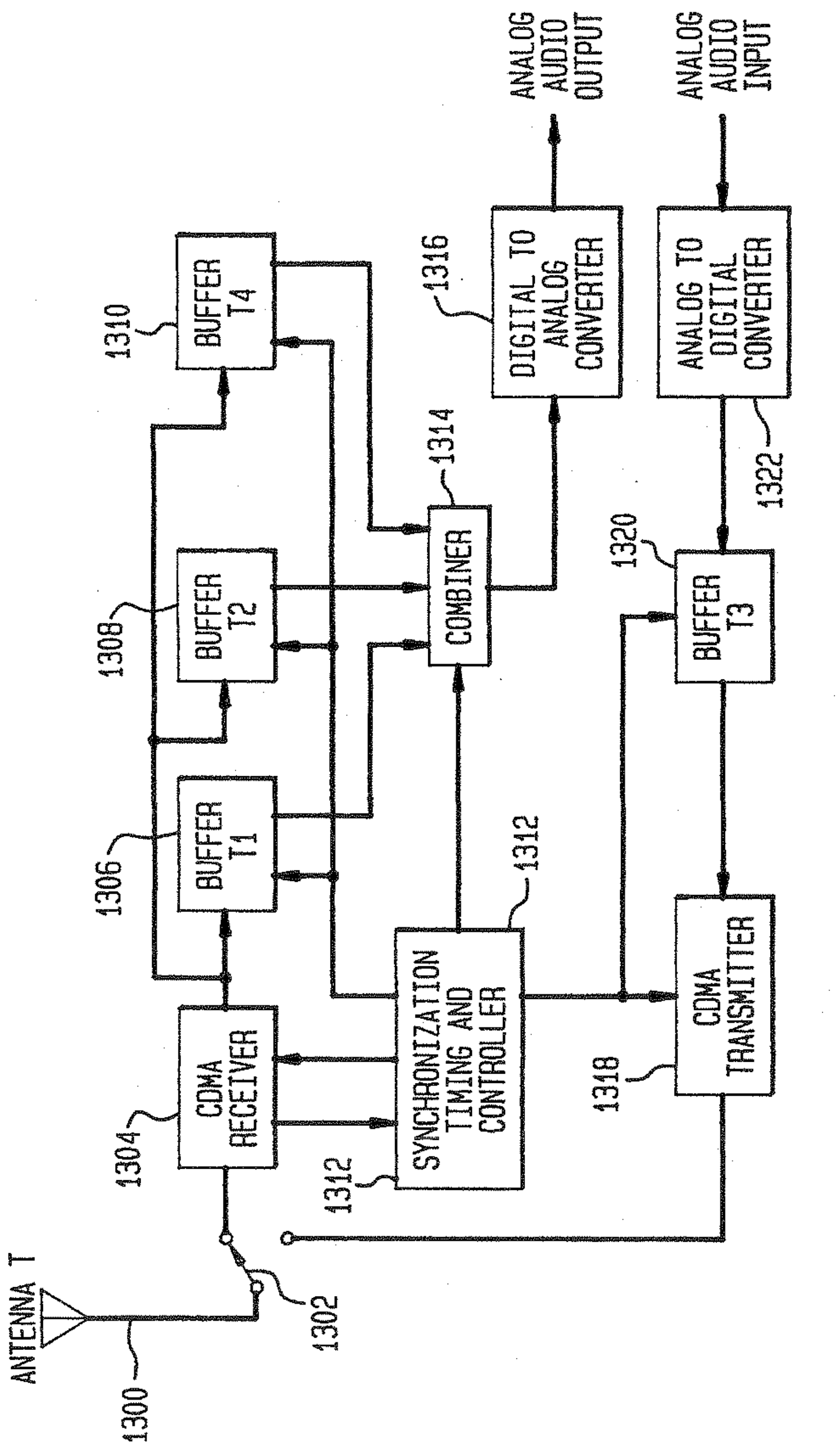


FIG. 14

CENTRALIZED AND INTEGRATED TRANSFER STATION

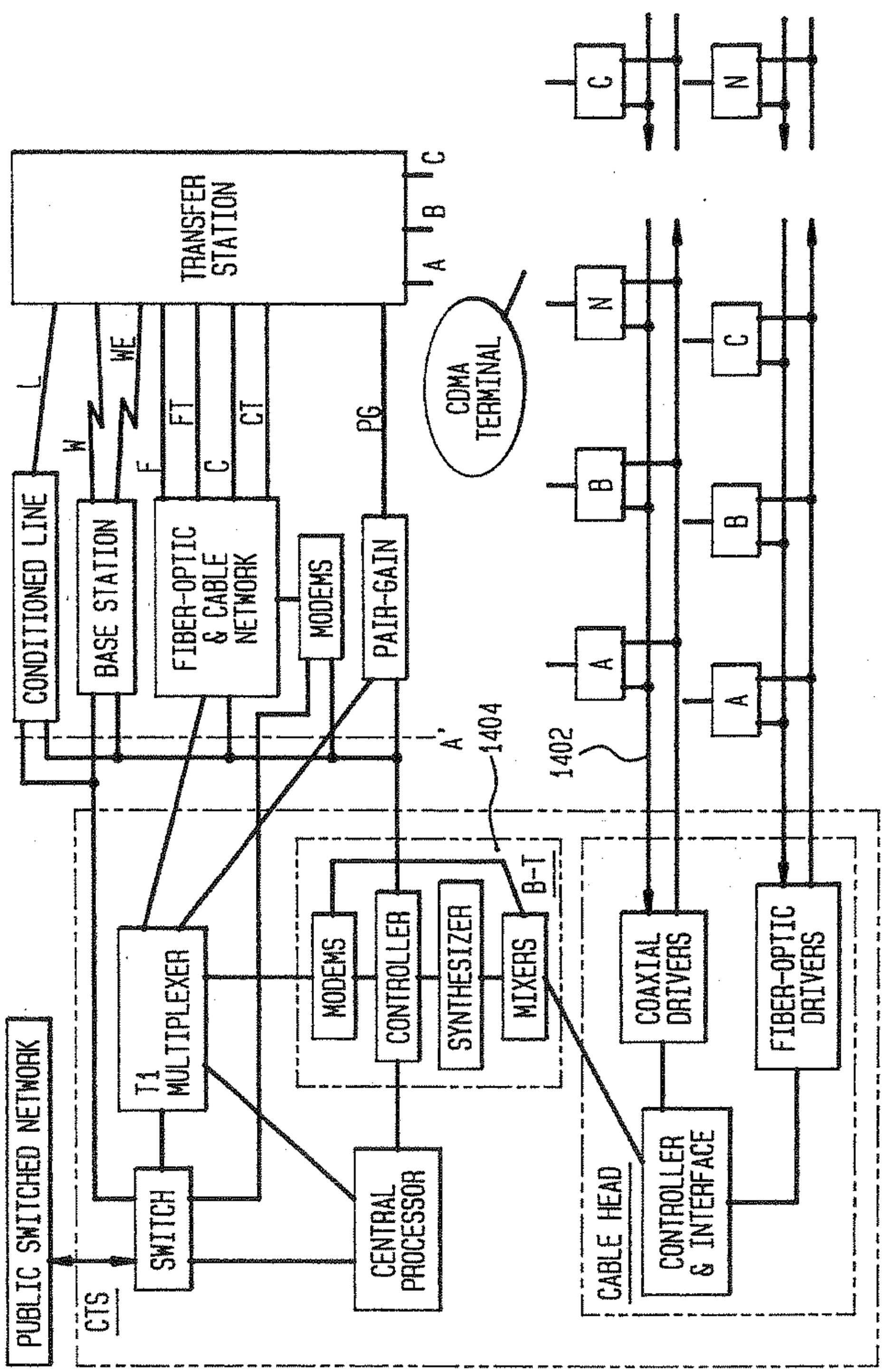


FIG. 15

TRANSFER STATION ANTENNA IMPLEMENTATION

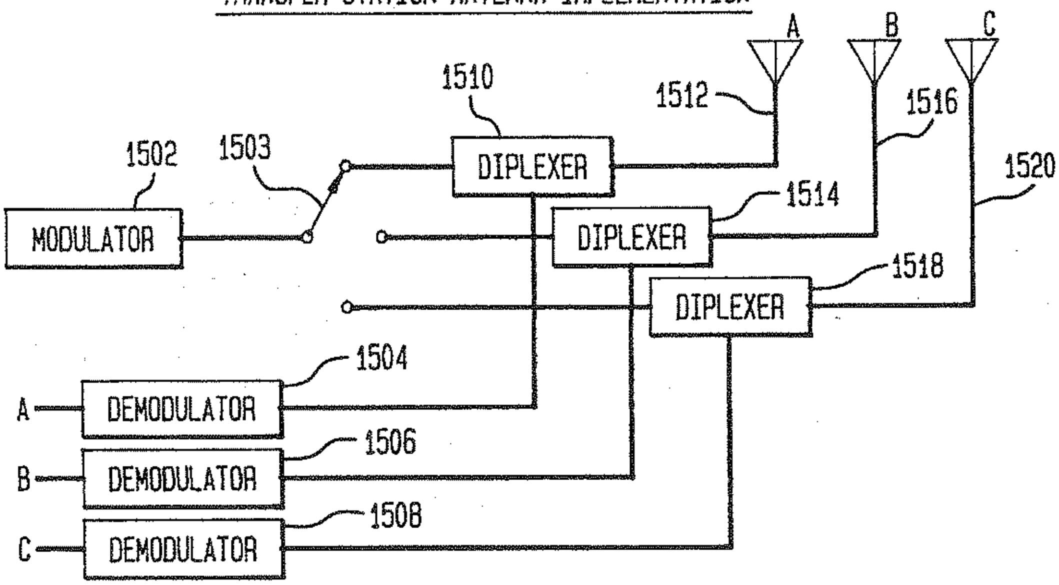


FIG. 16

DISTRIBUTED ANTENNA IMPLEMENTATION USING CABLE OR FIBER-OPTIC CABLE

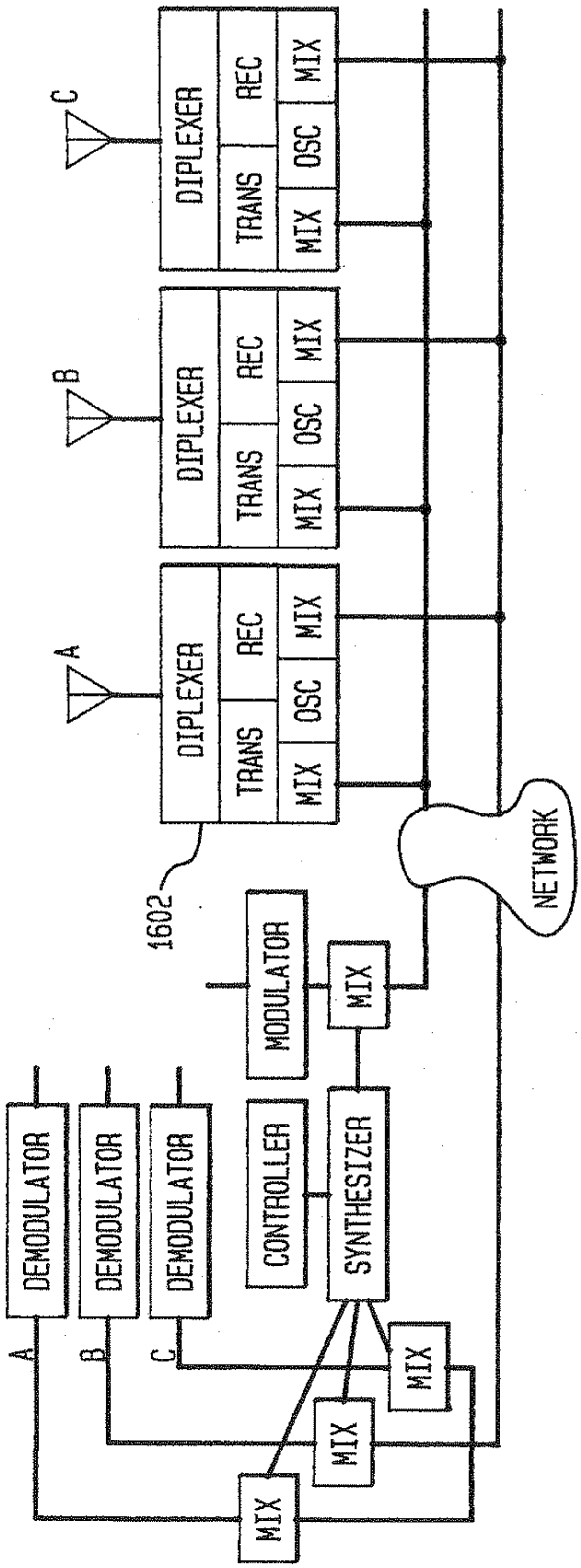
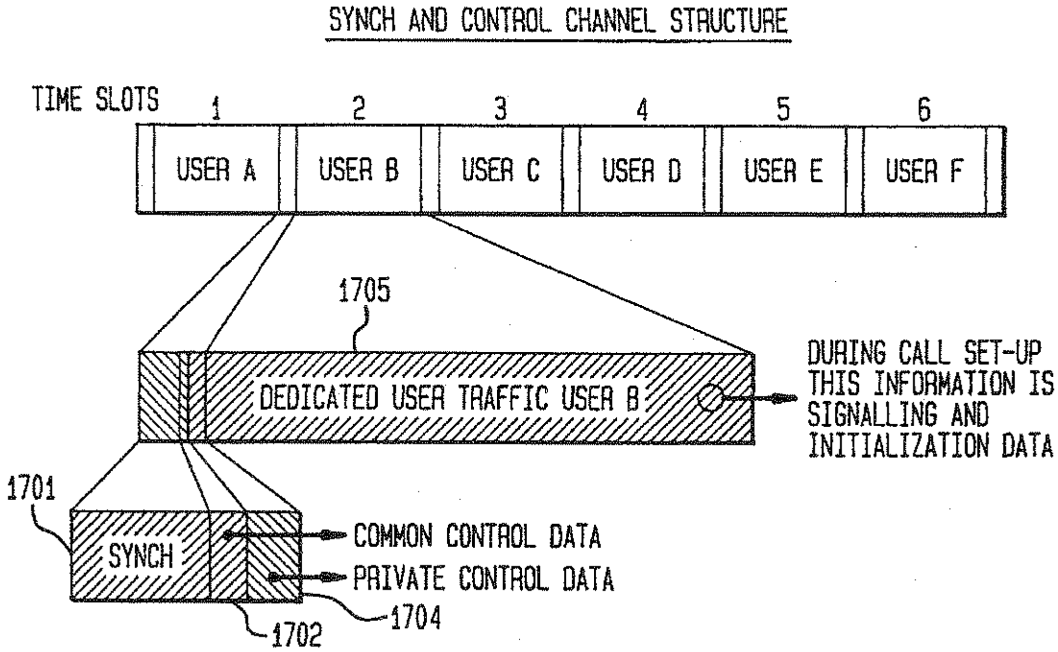


FIG. 17



SYNCH AND CONTROL CHANNEL STRUCTURE
TIME SLOTS
1
2
3
4
5
6
USER A
USER B
USER C
USER D
USER E
USER F
1705
DEDICATED USER TRAFFIC USER B
DURING CALL SET-UP THIS INFORMATION IS SIGNALLING AND INITIALIZATION DATA
1701
SYNCH
COMMON CONTROL DATA
PRIVATE CONTROL DATA
1704
1702

FIG. 18

TIME CALIBRATION FOR DISTRIBUTED ANTENNA IMPLEMENTATION

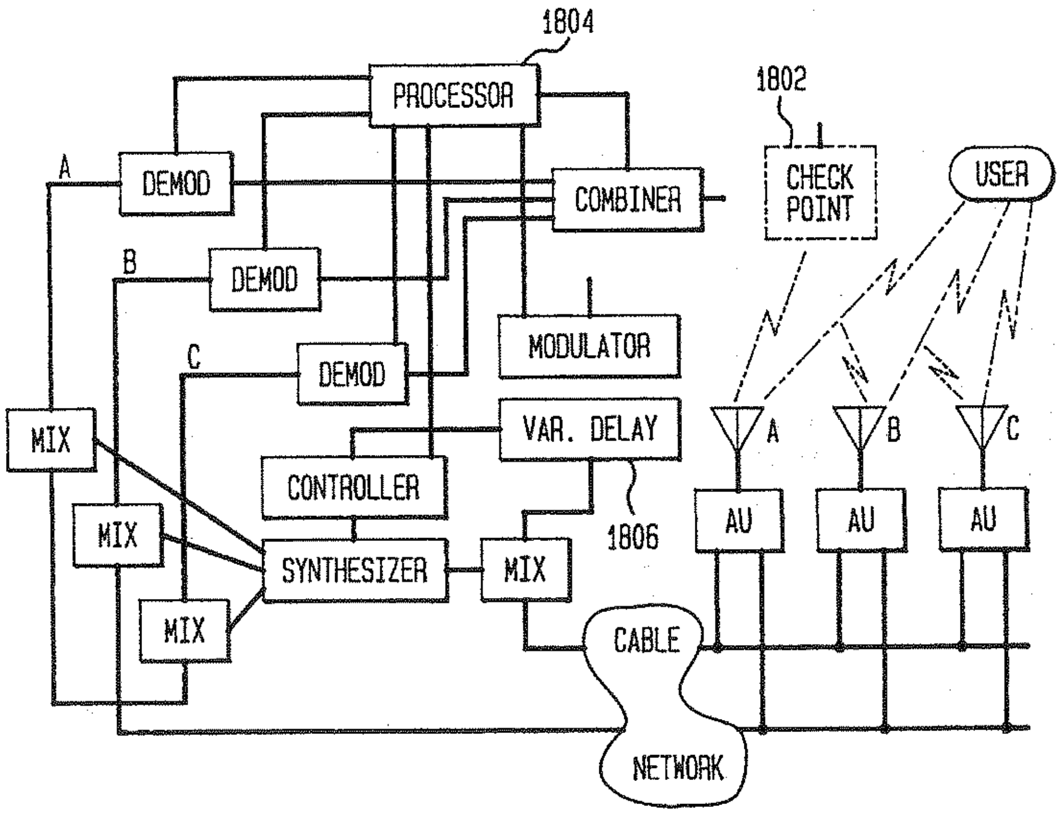


FIG. 19

LOCATION CENTER EXTERNAL TO COMMUNICAITON SYSTEM

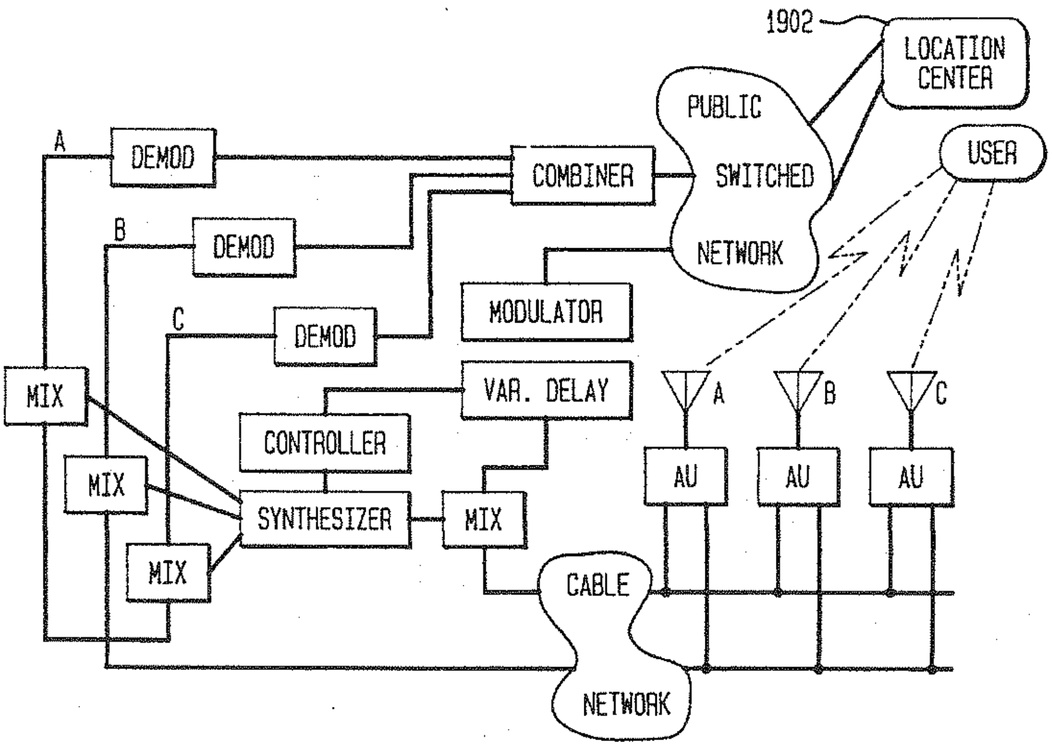


FIG. 20

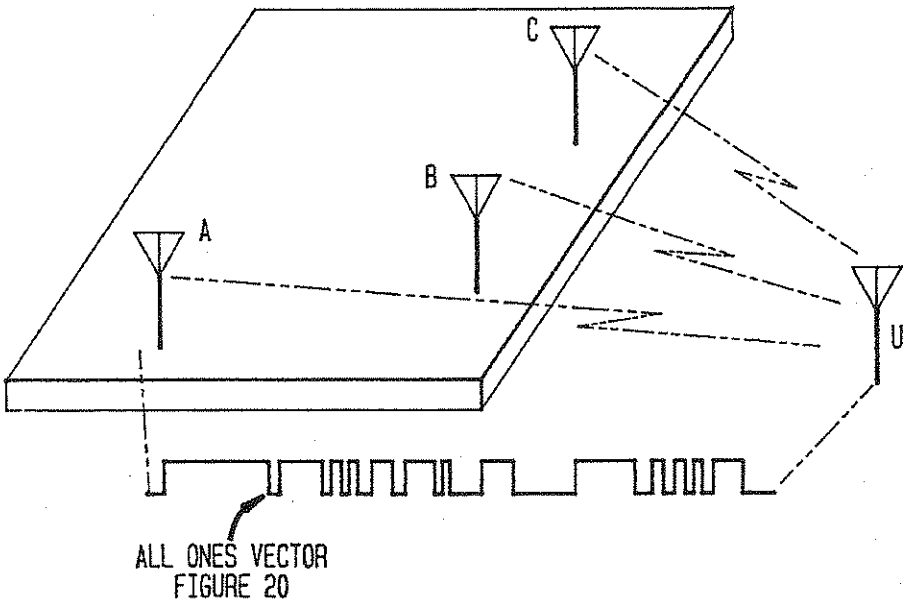

C
B
A
U
ALL ONES VECTOR
FIGURE 20

FIG. 21

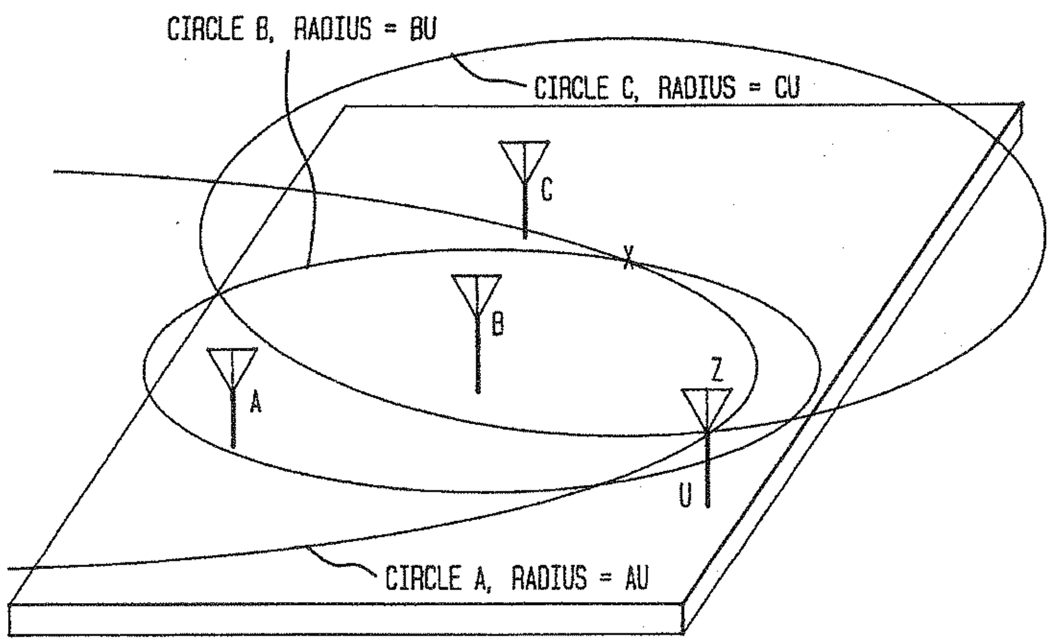

CIRCLE B, RADIUS = BU
CIRCLE C, RADIUS = CU
C
X
B
Z
A
U
CIRCLE A, RADIUS = AU

FIG. 22

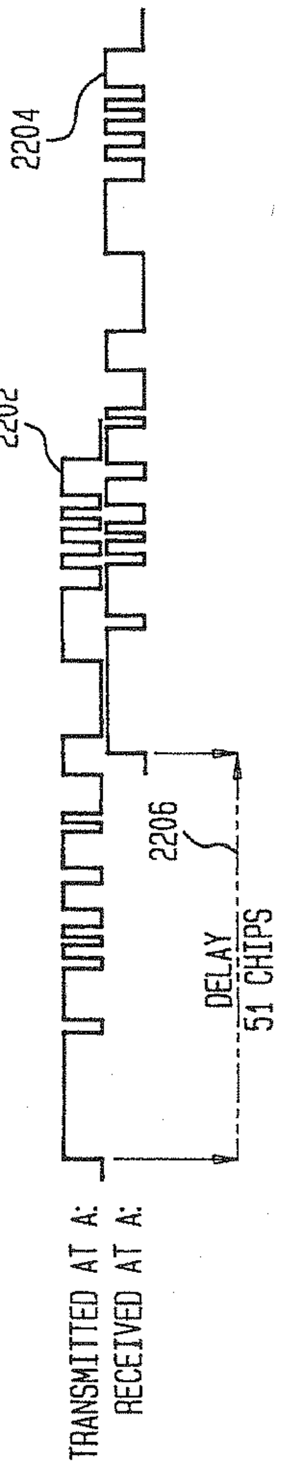
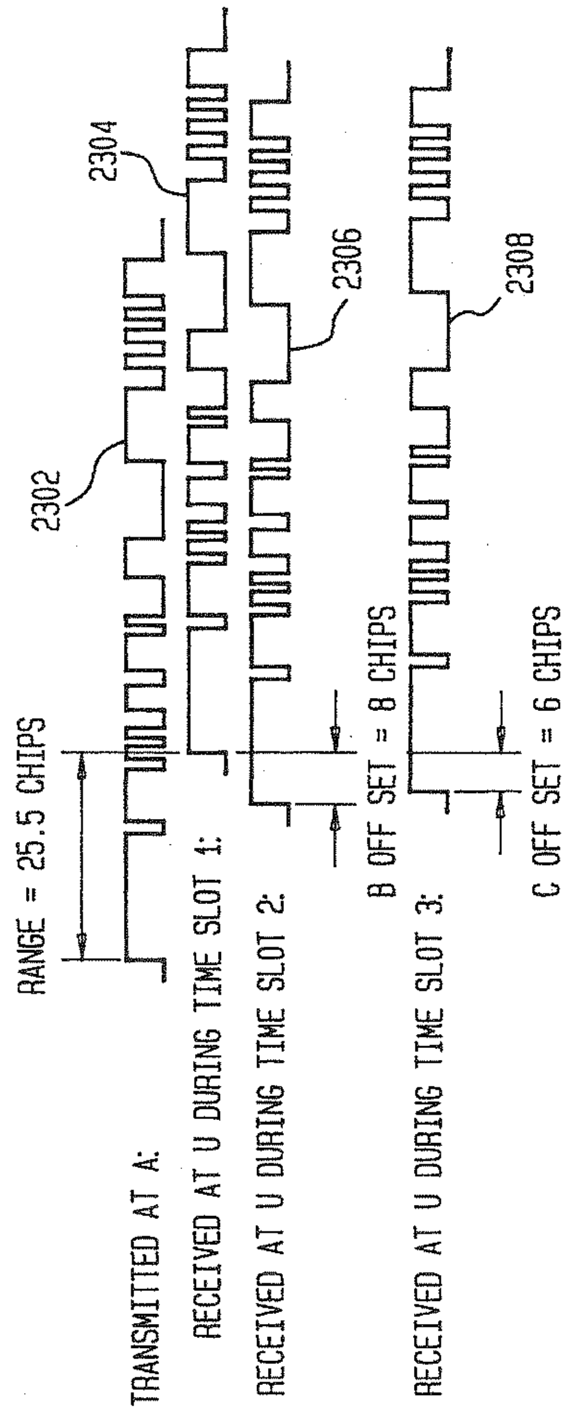

TRANSMITTED AT A:
RECEIVED AT A:
2202
2204
2206
DELAY
51 CHIPS

FIG. 23


RANGE = 25.5 CHIPS
TRANSMITTED AT A:
2302
RECEIVED AT U DURING TIME SLOT 1:
2304
RECEIVED AT U DURING TIME SLOT 2:
2306
B OFF SET = 8 CHIPS
RECEIVED AT U DURING TIME SLOT 3:
2308
C OFF SET = 6 CHIPS

WIRELESS TELEPHONE DISTRIBUTION SYSTEM WITH TIME AND SPACE DIVERSITY TRANSMISSION FOR DETERMINING RECEIVER LOCATION

FIELD OF THE INVENTION

The present invention relates to two way wireless communication systems. In particular, the present invention relates to wireless telephone systems with space diversity antennas and time diversity signal transmission for reducing signal fading and measuring subscriber location.

BACKGROUND OF THE INVENTION

Wireless radio communication is subject to the adverse effects of signal fading, in which the signal level at the receiver temporarily loses strength for a variety of reasons, such as from variable multipath reflections causing signal cancellation, time varying transmission loss due to atmospheric conditions, and mobile receiver movement introducing obstructions into the signal path, and the like. Signal fading causes poor reception, inconvenience, or in extreme cases, a loss of call connection.

It is known to use various forms of signal diversity to reduce fading. For example, as indicated in U.S. Pat. No. 5,280,472, signal diversity mitigates the deleterious effects of fading. There are three major types of diversity: time diversity, frequency diversity and space diversity.

Time diversity is obtained by the use of repetition, interleaving or error correction coding, which is a form of repetition. Error detection techniques in combination with automatic retransmission, provide a form of time diversity.

In frequency diversity, signal energy is spread over a wide bandwidth to combat fading. Frequency modulation (FM) is a form of frequency diversity. Another form of frequency diversity is code division multiple access (CDMA) also know as spread spectrum. Due to its inherent nature as a wideband signal, CDMA is less susceptible to fading as compared to a narrow band modulation signal. Since fading generally occurs in only a portion of the radio spectrum at any one given time, a spread spectrum signal is inherently resistant to the adverse effects of fading.

Space diversity is provided by transmitting or receiving the same signal on more than one geographically separated antennas. Space diversity provides alternate signal paths to guard against any one path being subject to fading at any one time. Space diversity also creates some time diversity since the receiver receives the same signal separated by small propagation delays. The difference in propagation delay requires that the receiver be able to discriminate between the arriving signals. One solution is to use multiple receivers, one for each arriving signal. For instance, it is known from U.S. Pat. No. 5,280,472 to deliberately introduce relatively small delays compared to an information symbol, into a space diversity multiple antenna CDMA system in order to create artificial multipath time diversity signals greater than one chip delay up to a few chips. CDMA systems are capable of discriminating between identical plural signals arriving at the receiver with different propagation delays greater than one chip delay. Such receivers are known as Rake receivers. However, prior art systems require multiple CDMA receivers, one CDMA receiver for each separate received CDMA signal. It is desirable to provide a system for receiving time diversity CDMA signals which does not require multiple CDMA receivers.

Measuring or determining the location of mobile units is well known. In some systems, fixed antennas measure the mobile location. In other systems, the mobile unit determines its location from multiple received signals. If the system is two way, the communication link permits both the mobile subscriber and the fixed system to exchange location data. Various known systems use satellites or multiple antennas to provide information on the location of a mobile subscriber. For example, multiple directional receiving antennas can be used to triangulate the position of a mobile transmitter. In such systems, the stationary receivers determine the mobile subscriber location; in other systems, the mobile subscriber determines its location from the received signals. For example, the Global Position System (GPS) is a multiple satellite system providing signals which permit a mobile subscriber station to determine its position in latitude and longitude. However, both satellite systems and the GPS receivers for receiving satellite signals tend to be expensive.

The combination of a GPS receiver and a cellular telephone is shown in U.S. Pat. No. 5,223,844. Such combination provides useful services, as for example a security alarm service to deter car theft, in which tripping the alarm also alerts the security service to the location of the car. Generally, it is desirable to provide a system which combines telephone or data service with location measurement at a reasonable cost.

It is desirable to provide a system of time diversity signals using time division multiple access (TDMA) in various combinations with CDMA and space diversity antennas, to provide a variety of systems which resist fading, reduce receiver cost, and provide location measurement for mobile subscribers.

SUMMARY OF THE INVENTION

The present invention is embodied in a wireless communication system in which time diversity and space diversity is used to reduce fading and simplify receiver design. The present invention is further embodied in a wireless communication system in which time division signals are code division (spread spectrum) multiplexed onto space diverse antennas to provide a wireless communication system with the ability to determine subscriber location using the same communication signals which are used for the primary wireless communication.

Specifically, a data packet which for example may carry telephone voice traffic, is transmitted at three different times from three different antennas. The receiver thus receives the same data packet at three different times from three different antennas. The receiver uses the best data packet or combination of the data packets to reduce the effects of fading.

In addition, the receiver uses the absolute and extrapolated relative time of arrival of the three data packets to determine its location from the three transmitting antennas. First, absolute range to one antenna is determined by the time required for a round trip message. Then, the relative time of arrival of data packets, referenced to a universal time, from the two other antennas indicates the relative distances as compared to the first antenna. Since all three transmitting antennas are at known fixed locations, the receiver computes its own location as the intersection of three constant distance curves (in the two dimensional case, circles, or in the three dimensional case, the intersection of three spheres). In the alternative, the mobile subscriber station provides raw delay measurement data back to a fixed station, or location service center, which computes the mobile subscriber location.

More particularly, the present invention is embodied in a system using CDMA to modulate a TDMA signal which is transmitted from three space diversity antennas. In a first embodiment, the TDMA signals are used to transmit multiple repetitions of the same data packet from a transfer station with three space diversity antennas. In a second embodiment, the TDMA signals are used to transmit multiple repetitions of the same data packet from three transfer stations each transfer station including one of the three space diversity antennas. The data packets could either be identical, or could carry substantially the same information, but modulated with different spreading codes or different segments of the same spreading code.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 is a system diagram of a wireless telephone distribution system including a first embodiment of a transfer station in accordance with the present invention.

FIG. 2 is a block diagram of a first embodiment of a wireless telephone distribution system in accordance with the present invention.

FIG. 3 is a system diagram of a first embodiment of a wireless telephone distribution system in accordance with the present invention.

FIG. 4 is a system diagram of a wireless telephone distribution system including a second embodiment of a transfer station in accordance with the present invention.

FIG. 5 is a system diagram of a second embodiment of a wireless telephone distribution system in accordance with the present invention.

FIG. 6 is a block diagram of a second embodiment of a wireless telephone distribution system in accordance with the present invention.

FIG. 7 is timing diagram of a time division multiplex signal which modulates a code division multiplex signal in accordance with the present invention.

FIGS. 8 and 9 are a block diagram of a first embodiment of a transfer station in accordance with the present invention.

FIG. 10A is a time slot assignment diagram of a wireless telephone distribution system in accordance with the present invention illustrating the time division multiplexing and code division multiplexing for 6 simultaneous calls.

FIG. 10B is a time slot assignment diagram of a wireless telephone distribution system in accordance with the present invention illustrating the time division multiplexing and code division multiplexing for 12 simultaneous calls.

FIGS. 11A and 11B are a time slot assignment diagram of a wireless telephone distribution system in accordance with the present invention illustrating the time division multiplexing and code division multiplexing for 24 simultaneous calls.

FIG. 12 is a block diagram of a second embodiment of a transfer station in accordance with the present invention.

FIG. 13 is a block diagram of a subscriber station in accordance with the present invention.

FIG. 14 is a block diagram of a centralized and integrated transfer station in accordance with the present invention.

FIG. 15 is a block diagram of a transfer station antenna implementation.

FIG. 16 is a block diagram of a distributed antenna implementation of the present invention using coaxial cable or fiber optic cable.

FIG. 17 is timing diagram of a time division multiplex signal which is modulates a code division multiplex signal in accordance with the present invention.

FIG. 18 is system diagram illustrating a distributed antenna implementation of the present invention.

FIG. 19 is a block diagram illustrating a system in accordance with the present wherein the location center is external to the communication system.

FIG. 20 is an illustration of a system in accordance with the present invention for determining location of a mobile subscriber station.

FIG. 21 is a system in accordance with the present invention illustrating a method for determining location of a mobile subscriber station.

FIG. 22 is a timing diagram illustrating a method for determining the distance from a subscriber station and to a transmitting transfer station.

FIG. 23 is a timing diagram illustrating a method for determining the relative distances from a subscriber station to two transmitting transfer stations.

DETAILED DESCRIPTION

SYSTEM DESCRIPTION—FIRST EMBODIMENT FIGS. 1, 2, 3, 8, 9

In a first embodiment of the invention shown in FIG. 1, a mobile user having an antenna 10 is coupled to a CDMA transfer station 14. The CDMA transfer station 14 further includes an antenna T, 16, antenna A, 11, antenna B, 12, and antenna C, 13. Antennas A, B and C can be mounted either on separate structures as is shown, or on a single mast. The only physical requirement is that the space between antennas should be sufficient for uncorrelated space diversity. While a quarter wavelength spacing may be sufficient, at least ten wavelengths is preferable. At 1 GHz, 10 wavelengths is about 30 feet, while at 5 GHz, 10 wavelengths is about 6 feet.

The mobile subscriber antenna 10 (also referred herein as the user terminal antenna, or the subscriber station antenna, or simply antenna U) is coupled by a bidirectional radio link to antennas A, B and C. The CDMA transfer station 14 is further coupled by a bidirectional radio link through antenna T through appropriate switching to the public switch telephone network.

In operation, forward channel telephone voice traffic received in data packets on antenna T is transmitted on antenna A during time slot 1, repeated on antenna B during time slot 2, and further repeated on antenna C during time slot 3. All three repeated data packets are sequentially received on antenna 10. In the reverse direction, data packets representing telephone voice traffic transmitted from antenna 10 are substantially simultaneously received on antennas A, B and C. The CDMA transfer station 14 further retransmits data packets received in the reverse direction through antenna T back to the telephone network.

FIG. 2 is an overview diagram of a system in accordance with the present invention that includes the different interconnections between the supporting network, i.e., between the public switched network 20 and switching center and central processor 22, and the CDMA transfer stations 26, 28, 30, 32, 34, 36 and 38.

The user at CDMA subscriber station 42 is linked by antenna 10 to the CDMA transfer station 38 through antennas A, B and C. Antenna T, 39 on CDMA transfer station 38 carries wireless TDMA telephone voice traffic to antenna 25 on base station 24. Each of the other CDMA transfer stations are coupled to the switching center 22 by a variety of

interconnection means. Connection means W between TDMA base station 24 and CDMA transfer station 36 is a wireless means, having a TDMA channel structure with six TDMA slots. The wireless TDMA distribution interconnection WE may be a commercially available wireless local loop system such as the Ultraphone® digital radio telephone system provided by Interdigital Communications Corporation. The TDMA time slot structure is carried through the transfer station to become the time slot structure for the slotted CDMA signal on the output. Connection means WE is the same as connection W except there are four W modules operating in parallel to provide a basic connectivity for 24 voice channels. Connection means F uses a fiberoptic cable that connects between the switching center 22 to the CDMA transfer station 32 without going through a wireless base station. Since connection means F (fiberoptic cable) incorporates a modem with a TDM/TDMA channel structure similar to W and WE it readily interfaces with the transfer station. Connection FT (fiberoptic cable carrying standard T1 multiplex) between switching center 22 and CDMA transfer station 30 is a fiberoptic cable that uses a standard T1 multiplexer as the channel combining means. Therefore, the transfer station that handles the WE connection means could readily be adapted to operate with the FT connection means. Connections C (coaxial cable) to CDMA transfer station 26, and CT to CDMA transfer station 28, (coaxial cable carrying T1 standard multiplex) are cable means that function like F and FT respectively. Connection means L to CDMA transfer station 36 is a conditioned line that carries up to a 100 kb/s data stream that has the same structure as the wireless TDMA, connection means W. Connection means LE (not shown) utilizes 4 conditioned lines to function in the same way as connection means WE. Connection means PG to CDMA transfer station 34 is a pair gain capability that is interfaced into a transfer station.

Using a combination of over the air and fiberoptic/cable media, to connect to the transfer stations, and a common output air interface, between the transfer stations and the CDMA user terminals, results in a flexible rapid response and economical solution. In addition, normal telephone lines conditioned to handle 64 kb/s to 100 kb/s could also be used to replace the TDMA wireless input to the transfer station. It also is very cost effective to connect the input side of the transfer station to the output of a pair gain module. Since the air interface remains the same for all these interconnection means, this extended concept becomes a very cost effective solution and transition vehicle.

In the system diagram of FIG. 3, telephone voice traffic through the public switched network 20, is coupled to a TDMA base station 24 having antenna 25 for the transmission and reception of TDMA signals. A plurality of CDMA transfer stations 44, 46, 48, 50 and 52 provide wireless telephone service for a plurality of subscribers 45 and 47. Each CDMA transfer station includes an antenna T for receiving and transmitting TDMA signals, as well as separate antenna A, antenna B and antenna C for communicating with mobile subscribers 45 and 47. By way of example, the TDMA base station 24 may have a range of 35 mile radius covering numerous CDMA transfer stations. Each CDMA transfer station may typically have a range of five miles and be spaced three miles apart to provide cellular coverage for the entire area. Subscriber 45 will be served by CDMA transfer station 46, while subscriber 47 will be served by CDMA transfer station 50. As subscribers move about the system, a different CDMA transfer station will be assigned to serve that subscriber.

An alternate embodiment capitalizes on the rich connectivity described above to more widely distribute the three

antennas that are used to give transmission space diversity. The wider distribution allows compensation for not only multipath fading, but fading due to blockage. For instance if the CDMA user (antenna 10 in FIG. 1) goes behind a building or hill the signal from all three space diversity antennas, on a single transfer station, would fade.

However, if the energy in each time slot was transmitted from different transfer stations as in FIG. 4, there is a high probability the user terminal would not be blocked from all three transfer stations at the same time. Therefore, it is possible to randomize the effects of fading due to blockage and be more similar to multipath fading. Randomization is accomplished by having the central controller assign the different time slots on an individual basis during the call setup process. When implemented using a W or WE connection means, there is little impact on the capacity between the base stations and the transfer stations, but it would increase the number of TDMA receivers. However, there is also a diversity improvement on the base station to transfer station link. Generally speaking, the impact on the other hard wired connection means is even less. A major advantage of using multiple transfer stations as transmission diversity sources is that it allows the user CDMA receiver to evaluate the quality of the signal from each transfer station and request a handoff for individual time slots as better links are found, providing a highly reliable and smooth transition as a user passes through an area.

SYSTEM DESCRIPTION—SECOND EMBODIMENT FIGS. 4, 5, 6, 12

FIG. 4 illustrates a wireless telephone distribution system with enhanced space diversity. As before, a mobile user antenna 10 is coupled to antenna A during time slot 1, antenna B during time slot 2 and antenna C during time slot 3. However, each of antennas A, B and C are mounted on separate respective CDMA transfer stations 54, 56 and 58. In particular, an antenna A, 60 is provided on CDMA transfer station 54, antenna B, 68 is provided CDMA transfer station 56, and antenna C, 64 is provided on CDMA transfer station 58. Each of the respective transfer stations 54, 56 and 58 are coupled through respective antennas 62, 70 and 66 to the TDMA wireless digital telephone system. The signals received from antennas A, B and C by the subscriber station antenna 10 are similar to that received in the configuration of FIG. 4. However, due to the separation of antennas A, B and C, at separate CDMA transfer stations 54, 58, 58, signal diversity both transmitting and receiving, is vastly improved.

The system configuration of FIG. 6 is similar to that of FIG. 2 with the exception that each CDMA transfer station has either an antenna B, or antenna B or an antenna C. For example, CDMA transfer station A, 108, has a separate antenna A, 109. The CDMA transfer station 106 has an antenna B, 107. Similarly, CDMA transfer station 104 has an antenna C, 105. Thus, the antenna 10 of CDMA subscriber station 112 receives signals from each of CDMA transfer stations 108, 106 and 104. The received signals are time division multiplexed in the sense that only one of antenna A, B or C is transmitting to antenna 10 at any one time. During transmission, however, antennas A, B and C provide multiple code division multiplexed signals to other users.

In this embodiment, each transfer station has only one type of antenna: either antenna A, antenna B or antenna C. A system arrangement covering a service area is illustrated in FIG. 5. As before, the public switch network 72 is coupled

to a TDMA base station 74 having a transmitting antenna 75 covering an area of approximately a 35 mile radius. Throughout the service area, CDMA transfer stations are spaced apart in one direction 84, and in another direction 86 are positioned to cover the service area. For illustration, a regular placement is shown. In practice, the CDMA transfer stations are placed so as to provide coverage whereby a plurality of subscribers 88, 90 are always within range of an A, B and C antenna. For example, CDMA transfer stations 76 and 82 are antenna A type, while CDMA transfer station 80 is an antenna C type and CDMA transfer station 78 is an antenna B type. Thus, subscriber 88 receives signals from CDMA transfer stations 76, 78 and 80, while subscriber 90 may receive signals from CDMA transfer station 82, 78 and 80.

A time slot structure for use in the present invention is shown in FIG. 7. Six time slots are used. Time slots 1 and 2 are used to receive, followed by time slot 3 wherein the subscriber station transmits, followed by time slot 4 also used for receiving. During time slot 5 and 6 the CDMA receiver scans the transmission from other transfer stations.

CALL ESTABLISHMENT

When a circuit is to be established or transferred, the base station assigns a base station and transfer station frequency pair, a slot and a PN sequence. It then transmits to the transfer station all of these assignments and identifies which subscriber is to use the circuit. During call setup, the transfer station passes on to the desired subscriber station, the slot and PN sequence assignments. For example, see FIG. 17 where the TDMA time slots 1 through 8 are associated with users A through F, respectively. In a given time slot, e.g., time slot 2, the message to user B contains synchronizing information 1701, common control data 1702 for system wide functions, private control data 1704 and dedicated user traffic 1705 for user B. The dedicated user traffic 1705 is used during call setup to transmit signalling information and initialization data.

FORWARD PATH

Signal compression and decompression, plus added bits for forward error correction (FEC) is performed at the base station. In the forward direction, (to the subscriber station), the base station transmits continuously but the information in each slot is directed to a particular subscriber station.

By way of example, the base station may transmit the information during slot 1 on frequency fa. The transfer station receives the information by demodulating the signal on frequency fa during slot 1, and regenerating the information only at the symbol or bit level. The transfer station does not perform any decoding (i.e., error correction, compression or decompression). The transfer station design is thus simplified by accepting the already coded signal from the TDMA base station. After regeneration at the symbol level, the received TDMA signal is combined with the assigned PN sequence and retransmitted from the transfer station as a CDMA signal on frequency fp without any intentional delay to antenna A. The transfer station further stores the information received from the base station in a memory buffer. At the end of the antenna A transmission, the information bits stored in memory buffer are modulated onto a continuation of the PN signal and broadcast through an appropriate transmitter to antenna B. Thus, the identical information signal using the same PN sequence, but incremented a fixed number of chips, is transmitted at antenna B. The relative position, or phase of the PN sequence relative to the transmitted information is different. At the conclusion of the first repeat, information in the time slot buffer is read out a third time to provide a third repetition of the information, modulated by a continuation of the PN sequence, with still a different phase, through an appropriate transmitter to antenna C.

SUBSCRIBER STATION PROCESSING

The subscriber station, using the correct CDMA code, receives during each of the three slots containing information signal repetition, so that it receives three identical repeats of the data packet from three antennas located in different locations. The subscriber station then compares the three receptions and selects the one with the best quality which may be based on bit error rate, phase distortion, signal to noise ratio, etc. Thus, spacial transmit diversity is achieved. Only one antenna is needed at the subscriber station. The subscriber station demodulates and decodes the signal, performs error correction, decompression, etc. A maximum likelihood combiner may be used to combine the power from all three time slots. Ideally, the energy of received data packets is combined in a maximal manner before making a hard decision.

During the third time slot T3, the subscriber station transmits back to the transfer station using a similar PN sequence as it received. The PN sequence may be the one derived from reception (after regeneration) or it can be locally generated on the basis of the original code received during call setup. Since the subscriber station does not transmit during the same time period as it receives, no diplexer or notch filter is needed. A simple T/R (transmit/receive) switch is used to switch the antenna between transmit and receive. Only one receiver is necessary in the subscriber station to achieve three branch diversity. The three chains needed by a Rake receiver, are not needed in the present invention.

Furthermore, the benefits of triple time and space redundancy, with some frequency protection provided by the expanded spectrum, are not obtained by adversely affecting capacity. The three branch diversity typically achieves a reduction for deep fades of at least 10 dB (a factor of 10x). While the three transmitted repetitions of the same information signal increases the interference level by a factor of 3 (about 5 dB), because the fades are 10 dB less, the transmitter power levels can be reduced by a factor of 10 (10 dB). Thus the overall amount of interference is reduced by a factor of 10/3 or 5 dB. Because the transfer station to subscriber link is operated in a self interference mode that means that about three times as many simultaneous subscriber circuits can be used than if diversity were not used.

RETURN PATH

In the reverse direction (subscriber station to transfer station), three receivers are connected respectively to the three antennas at the transfer station to provide conventional three branch spacial diversity. The same analysis regarding interference and the number of circuits available, applies to transmission in the reverse direction as well as in the forward direction, except that the information is transmitted only once and is received simultaneously on the three base station antennas.

In addition to increasing the number of subscribers per unit frequency, the present invention is cost effective. First the subscriber station needs only one receiver. Second, it

does not need a diplexer. Third, the transfer station does not need to decode or re-encode any signals. The number of subscribers per transmitter is the same, however, since spacial diversity is used in the reverse direction, the number of subscribers per receiver increased. Conversely, the noise of the subscriber station can be allowed to be higher if the full use of the increase in the number of subscribers is not fully utilized.

The signal received by the transfer station from the subscriber station is retransmitted (again with symbol or bit level regeneration but without decoding), from the transfer station back to the base station without intentional delay during the same slot. As long as the slot is within the same TDMA frame or at least with one frame's duration of the slot used from the base station to the transfer station, no additional delay is incurred by the use of the present system.

TRANSFER STATION—FIRST EMBODIMENT FIGS. 8, 9, 15

The CDMA transfer station has a TDMA input at antenna T. The output side of the transfer station at antennas A, B and C, uses a CDMA structure to reach a large number of subscribers in relatively densely populated areas. CDMA possesses several attributes that make it desirable for this application. The wideband signal is inherently robust in a multipath environment and it has the ability to overcome interference, intentional and otherwise. The possibility that selective fading will cause the entire spectrum to be suppressed decreases as the transmitted spectrum increases. A higher chip rate, or increased TW product, reduces the amount of fade margin that is required to achieve a specified level of performance.

Spread spectrum signals have inherent multipath protection to protect against fading. However, statistical models generally do not take into account the frequency of occurrence or the duration of the fades. The specific geometry at each location, and how the geometry is changing with regard to the receiver, determines the actual fading patterns. For small cells, with low antennas, the difference in path length for strong signals is very likely to be small. The result is flat fading. That is, the spectrum across ten or fifteen megahertz will fade at the same time. Therefore, it is not possible to use the inherent multipath protection characteristics of spread spectrum signals to protect against flat fading unless at least 25 or 30 MHz of spectrum is available. In addition, there is often no multipath of consequence that would have enough delay to gain an advantage from an additional Rake receiver. Even so the use of real or artificial multipaths, requires additional receiver/correlators in the CDMA user terminal. Therefore, to maintain reliable operation using CDMA only, at least 15 dB of margin is required to be added to the link power allocation, particularly to account for the situation where a mobile user stops in one of the nulls or a fixed user shifts location geometry slightly.

The present invention utilizes the other important characteristic of spread spectrum systems, the ability to overcome interference, as the technique to combat the difficult multipath situations. The capacity of a CDMA system is limited by the amount of interference that is received by the desired receiver. As long as the TW product is great enough to bring the desired signal up out of the interference it doesn't matter what the transmitted data rate actually is. Therefore, with the present invention the transmitted information rate is increased to allow the transmitted signal to be repeated three times from three different antennas, thus obtaining transmission triple diversity which allows the transmitted power margin to be reduced by at least 10 dB for a high performance link. Therefore, even though additional interference is introduced into the links, the CDMA processing gain readily overcomes the adverse impact. That is, the gain from the triple diversity far exceeds, in a high quality system, the loss due to added interference.

A block diagram of transfer station in accordance with the first embodiment of this invention is shown in FIG. 8 for the forward channel. The TDMA antenna T, **916**, is coupled through a transfer receive switch **918**, to a TDMA receiver **800**. The output of the TDMA receiver **800** is coupled to a demultiplexer **802**, the output of which is stored in time slot buffers **806**. A time multiplexer **808** accesses the contents of the time slot buffers **806** and provides data packets output to plural CDMA encoders **810** intended for antenna A transmission. The output of time multiplexer **808** also provides data packets output to plural CDMA encoders **812** intended for antenna C transmission. Similarly, the time multiplexer **808** provides data packets output to plural CDMA encoders **814** intended for antenna B transmission. Each of the plurality of CDMA encoders **810**, **812** and **814** are provided to respective CDMA transmitters **816**, **824** and **826**. Each of CDMA transmitters is coupled to a respective antenna **822**, **824** and **826** to provide respective antenna A, antenna B and antenna C transmissions.

The coordination of the timing and control of the TDMA receiver **800**, as well as the time slot buffers **806**, the time multiplexer **808** and each of the plurality of CDMA encoders, is controlled by a synchronization and control apparatus **804**. The synchronization and control apparatus **804** also provides a location identification (ID) representing the particular transfer station to the plurality of CDMA encoders **810**, **812** and **814** for inclusion on the transmitted signals at antennas A, B and C.

The transfer station of FIG. 8 also includes a CDMA receiver and TDMA transmitter **900**, which is shown in further detail in the block diagram of FIG. 9. The TDMA transmitter is coupled to antenna **916** through transmit receive switch **918**, while the CDMA receivers are coupled through respective diplexers to antenna A, antenna B and antenna C, as shown in further detail in FIG. 15.

FIG. 9 is a block diagram of a transfer station illustrating the structure of handling signals in the reverse channel. Antennas A, B and C, respectively shown as **822**, **824** and **826** are coupled to respective CDMA receiver A, **902**, CDMA receiver B, **904**, and CDMA receiver C, **906**. The output of the respective CDMA receivers A, B and C is fed to maximum likelihood combiner **908**, the output of which is provided to memory buffers and time slot multiplexer **910**. The memory buffers in time slot multiplexer **910** provide data packets to a TDMA transmitter **914** which is coupled through transmit receive switch **918** to antenna **916**. The TDMA receiver and CDMA transmitter **828** corresponding to the block diagram of FIG. 8 is coupled to the other terminal of transmit receive switch **918**.

FIG. 15 illustrates the antenna configuration of a transfer station permitting antenna A, antenna B and antenna C to be shared between TDMA and CDMA transmit and receive signals. Modulator **1502** is coupled through a time multiplexer **1503** to diplexers **1510**, **1514**, and **1518**, respectively coupled to antenna A, **1512**, antenna B, **1516** and antenna C, **1520**. The other input of diplexers **1510**, **1514** and **1518** is respectively coupled to the output of demodulator **1504**, **1506** and **1508**.

In the operation of FIG. 8, a TDMA signal received on antenna **916** is demultiplexed and placed in time slot buffers

806. A data packet intended for a given subscriber is selected by time multiplexer 808 during time slot 1 to encode a CDMA signal by one of plural encoders 810 for transmission on antenna A. The same data packet is again selected by time multiplexer 808 to encode a CDMA signal by one of plural encoders 812 during time slot 2 for transmission on antenna B. Finally, the same data packet is subsequently selected by time multiplexer 808 to encode a CDMA signal by one of plural encoders 814 for transmission during time slot 4 on antenna C.

In the reverse direction, and in reference to FIG. 9, the CDMA transmission from the subscriber station during time slot 3 is substantially simultaneously received on antennas 822, 824 and 826. Each of the CDMA receivers 902, 904 and 906 receive the same data packet. A maximum likelihood combiner 904 combines the power from all three time slots before making a hard decision. Generally speaking, the signal which is strongest and error free will be selected. After selection, the data packet is held in a memory buffer and time slot multiplexer 910 waiting to be placed in its appropriate time slot for transmission by TDMA transmitter 914 on antenna 916.

TRANSFER STATION—SECOND EMBODIMENT FIG. 12

A transfer station in accordance with the second embodiment of the present invention is shown in FIG. 12. In essence, this transfer station is similar to the transfer station of FIGS. 8 and 9 except that only one CDMA antenna, A, B or C, is provided. In particular, in FIG. 12 antenna 1200 is coupled through a transmit receive switch 1202 to a TDMA receiver 1204. The output of the TDMA receiver 1204 is demultiplexed in 1206 and placed in time slot buffers 1208. A data packet placed in time slot buffer 1208 is time multiplexed by multiplexer 1210 to one of a plurality of CDMA encoders 1212. The encoded CDMA signal is amplified in CDMA transmitter 1214, coupled through diplexer 1218 to antenna A, 1228.

Antenna A 1228 also operates to receive CDMA signals. Towards this end, a CDMA receiver 1226 is coupled to antenna A, 1228, through diplexer 1218 to provide received data packets in combiner and time slot buffers 1224. A time multiplexer 1222 takes the data packets in time slot buffers 1224 and composes a time multiplex signal to TDMA transmitter 1220 which is coupled through transmit receive switch 1202 to antenna 1200. The operation of the transfer station is controlled by a synchronization and control apparatus 1216 which also includes unique location identification (ID) for this particular transfer station, and call setup control parameters.

In operation, the transfer station receives TDMA signals on antenna T, 1200 which are demodulated in TDMA receiver 1204, and demultiplexed in demultiplexer 1206 for placement in time slot buffers 1208. The data packets in time slot buffers 1208 are transmitted on antenna A during time slot 1. Towards this end, time multiplexer 1210, CDMA encoders 1212 and the CDMA transmitter 1214 retrieve the respective data packets from time slot buffers 1208 and encode the appropriate data packet in a CDMA encoded signal on antenna A. On the return path, CDMA receiver 1226 receives signals simultaneously on antennas A, B and C during all time slots. The received data packets are demodulated by respective PN codes, and placed in time slot combiner buffers 1224, each time slot assigned to a different user. Thereafter, data packets are time multiplexed in multiplexer 1222 for transmission by the TDMA transmitter 1220 through the transmit receive switch 1202 on antenna 1200.

The Transfer Station is the conversion point for mapping the TDM/TDMA signal into a CDMA signal. The CDMA signal, when designed properly has superior performance against multipath interference. The input side of the transfer station is part of a structured distribution network. It is basically a tandem relay point in the network, that is, the address to the final CDMA user also includes the address of the intermediary point (the transfer station). Since, in the general case, the final CDMA user may move and access the network through another transfer point it will be necessary to provide the ability to enter the transfer station address independent from the CDMA users address. For fixed subscribers such as the TDMA subscriber station 40 in FIG. 2, this will not be an issue except for backup routing or for fade protection.

The preferred input network includes a number of base stations, transfer stations and TDMA user stations as shown in FIG. 2. Any time slot on any frequency could be assigned to any TDMA user or transfer station. To reduce the cost of the transfer station it is proposed that once a CDMA user is connected through a specific transfer station any additional CDMA users, assigned to that transfer station, also be assigned to a time slot on the same frequency as the first user. By properly managing these assignments the number of TDMA radio elements can be reduced significantly. The base station 24 or the switching center and central processor 22 will manage the radio resource and assign the frequencies, time slots and the PN codes, thus assuring efficient use of the spectrum and the radios. The frequency, time slot and PN code are all assigned during the initial call setup process.

The local transmissions on the output side of the transfer station are CDMA, but each subscriber is assigned a specific time slot of a time division signal. Therefore, the individual information rate is increased by the number of time slots. However, the total data rate for all subscribers stays the same and the total transmitted power for all signals remains the same, it is just redistributed. Since the individual time slots are turned off unless there is activity the transmitted power is reduced by approximately 3 dB for voice traffic. Because the same information is transmitted three times the average transmitted power is increased by 5 dB. Therefore, the total transmitted power from each transfer station is increased by 5 dB, transmitting three times, but also reduced by 10 dB, diversity improvement, resulting in a 5 dB overall reduction in average power. Overall, the interference introduced into other cells is reduced by 5 dB.

The base station (24 in FIG. 2) or the switching center and central processor (22 in FIG. 2) will also manage the handoff process. There will have to be at least four time slots to obtain diversity on the CDMA side and still have a time slot for the CDMA receiver to scan other transfer stations. Four time slots only provide dual diversity. With five time slots it is possible to achieve the desired level of triple diversity. Of course, by adding additional receivers in the CDMA user's terminal it will be possible to scan in parallel for better synch signals. However, adding another receiver in all the CDMA users terminals would be an expensive solution. Therefore, with three time slots there is only dual diversity and no handoff. With four time slots there is triple diversity for fixed CDMA subscribers and dual diversity for mobile CDMA subscribers. With five time slots there is triple diversity for both fixed and mobile CDMA users. With six or more time slots there is the opportunity to add flexibility to the channel structure. FIG. 7 shows the CDMA user terminal slot structure for six time slots.

The triple antenna structure at the transfer station is used on the return link by simultaneously listening to a single burst from each active subscriber, in his assigned time slot, on all three antennas, thus also achieving triple space diversity. The overall timing structure for the forward and reverse CDMA links, at the transfer station, are shown in FIG. 10A. For illustrative purposes six time slots have been shown, but as described previously any number of time slots, three or more, can be implemented, the upper reasonable bound being in the neighborhood of 32.

The order of transmission of the three active time slots can be distributed over the total number of time slots, and even more than three time slots could be used. With triple diversity the power transmitted from the CDMA user terminals can be reduced by at least 5 dB, probably more, but 5 dB is in keeping to match the performance of the forward link. In any case, the transmitted power is controlled and kept at the minimum level to maintain a high quality link. It is also possible, at higher frequencies, to achieve some antenna independence even on a relatively small radio or area. Therefore, a similar approach of the transmission space and time diversity, that is used on the forward link, may also be applied to the reverse link. Dual diversity should yield a significant improvement for most situations.

Each transfer station continuously transmits a spread spectrum channel for synchronization and control purposes. The synchronization and control channel identifies the particular transfer station and manages the user terminals as long as they are assigned to the transfer station. A large portion of the time the synchronization and control channel does not carry any user traffic. The synchronization and control channel can be a narrow band channel that can be easily acquired and tracked. The information bearing portion of the control signal has a preassigned time slot and includes system and signaling messages to all the users assigned to the particular area covered by that transfer station. The processing gain is sufficient to allow a transfer station to include several time slotted CDMA signals to be transmitted in parallel, thus allowing the antenna array to be shared. Also, only one synchronization and control channel is required for multiple slotted CDMA modules that are integrated at a single location.

SUBSCRIBER STATION FIG. 13

A block diagram of the subscriber station in accordance with the present invention is shown in FIG. 13. Antenna 1300 is coupled to CDMA receiver 1304 through transmit receive switch 1302. The output of CDMA receiver 1304 provides data packets to data buffers 1306, 1308 and 1310. A combiner 1314 selects and combines the data held in buffers 1306, 1308 and 1310 to provide an output to a digital to analog converter 1316, which also includes means for decompressing the compressed signal to provide an audio output. An analog audio input is provided to analog digital converter 1322, which also provides means for compressing the audio signal. The output of the analog to digital converter 1322 is a digital form of audio samples assembled as data packets in memory buffer 1320. A CDMA transmitter 1318 encodes the contents of memory buffer 1320 and provides a CDMA encoded signal through transmit receive switch 1302 to antenna 1300. The CDMA subscriber station is synchronized by a synchronization and timing controller 1312, which also measures signal delay for location measurement, described below.

In the forward direction, CDMA receiver 1304 receives three identical data packets placing one of the data packets during time slot T1 in buffer 1306, a second of the data packets during time slot T2 in memory buffer 1308, and a third data packet received during time slot T4 in memory buffer 1310. The combiner 1314 selects one or more of the contents of the memory buffers to be combined or selected as the best received data to be converted to an analog audio output of the output of digital to analog converter 1316. By using three time and space diversity data packets, the present system is less susceptible to fading and since the same receiver is used to demodulate all three samples, no complex signal strength balancing process is required.

In the reverse direction, the analog audio input to analog to digital converter 1322, which also includes a digital compression algorithm, provides a data packet to buffer 1320. During time slot T3 the CDMA transmitter 1318 encodes the contents of buffer 1320 for transmission as a CDMA signal on antenna 1300.

The simplification of the CDMA user terminal is a major consideration in the present system. The main simplification is the ability to time share the receiver, and particularly the correlator as it performs its different functions. The ability to transmit and receive at different times also simplifies the implementation of the small portable user terminal. The single receiver sequentially receives the three space diversity signals in the three different time slots and then moves to different codes to look for improved signals from other transfer stations. The same receiver is also used for the purpose of acquisition and tracking. Since the user terminal does not receive during the slot when it is transmitting there is no need for a diplexer and notch filter. Only a simple on/off switch is used. Since only one PN code is needed at a time, the PN code generation process is also greatly simplified. The baseband processing can be accomplished on a relatively low speed common processor.

In those time slots where the user terminal is not receiving or transmitting the receiver is free to look for the synchronization and control channels from other transfer stations. When the user terminal identifies a synchronization and control channel that is better than the one he is assigned, the user terminal sends a message to the network controller telling the controller that he has identified a potential candidate for handoff. The network controller uses this input, along with other information, to make the decision to handoff. The network controller sends the handoff message to the effected entities. The identity of the codes that are to be searched by the user terminal are provided by the network central controller through the transfer station where they are placed on the control channel.

TIME SLOT STRUCTURE FIGS. 10A, 10B, 11A, 11B, 17

The time slot assignment for multiplexing 6 simultaneous calls is shown in FIG. 10A. Time slots assignments for transmission 1002 and for reception 1004 are illustrated. The entry in each box contains the activity during the corresponding time slot. During time slot 1, antenna A transmits T1 to user 1, antenna B transmits T6 to user 6 and antenna C transmits T4 to user 4. At the same time, antennas A, B and C receive R5 from user 5. During the next time slot 2, antenna A transmits T2 to user 2, antenna B transmits T1 to user 1 and antenna C transmits T5 to user 5. At the same time antennas A, B and C receive R6 from user 6. Continuing across the diagram in FIG. 10A, during time slot 3, antenna A transmits T3 to user 3, antenna B transmits T2 to user 2 and antenna C transmits T6 to user 6. At the same time antennas A, B and C receive R1 from user 1.

Note that during time slot 3, none of the antennas A, B or C is transmitting to user 1. Instead, user 1 is transmitting and

the transfer station is receiving on all three antennas from user 1. However, during time slot 4, the third transmission to user 1 is transmitted. That is, during time slot 4, antenna A transmits T4 to user 4, antenna B transmits T3 to user 3 and antenna C transmits T1 to user 1. Time slots 5 and 6 are not directly used for data transfer to or from user 1. The time slot assignments shown in FIG. 10A, 10B, 11A and 11B are consistent with FIG. 7, wherein user 1 receives during time slots 1, 2 and 4, and transmits during time slot 3. The pattern can be seen in FIG. 10A slot assignments by looking for times when T1 is transmitted. Transmission of T1 appears in time slots 1, 2 and 4, on antennas A, B and C respectively. No transmission to T1 appears during T3, but reference to receiving time slots 1004 indicates that R1 is received from user 1 during time slot 3. Since in any given time slot, there are three transmissions and one reception simultaneously, at least 4 addressable CDMA PN spreading code sequences are required.

Thus, time division multiplexing is used in the sense that successive time slots carry data directed to different users. Code division multiplexing is used in the sense that during each time multiplexed time slot, multiple PN code sequences permit simultaneous communication with multiple users. The result is a time division multiplexed, code division multiplexed signal.

The time slot assignment for multiplexing 12 simultaneous calls is shown in FIG. 10B. Time slots assignments for transmission 1006 and for reception 1008 are illustrated. During time slot 1, antenna A transmits T1 to user 1 and T7 to user 7, antenna B transmits T6 to user 6, and T12 to user 12, and antenna C transmits T4 to user 4 and T10 to user 10. At the same time, antennas A, B and C receive R5 from user 5, and R11 from user 11.

The time slot assignment for multiplexing 24 simultaneous calls is shown in FIGS. 11A and 11B. FIG. 11A shows the transmission from the transfer station (forward direction), while FIG. 11B shows the transmission to the transfer station (reverse direction). Time slots assignments for transmission 1102, 1104, 1106 and for reception 1108 are illustrated. By way of example, during time slot 5, antenna A transmits T5, T11, T17 and T23 (i.e., T5 to user 5, T11 to user 11, etc.) Antenna B transmits T4, T10, T16 and T22. Antenna C transmits T2, T8, T14 and T20. At the same time, (during time slot 5), antennas A, B and C receive R3, R9, R15 and R21 (i.e., R3 from user 3, R9 from user 9, R15 from user 15 and R21 from user 21).

For FIG. 10A, one CDMA encoder per antenna is required to handle 6 simultaneous calls. In FIG. 10B, two CDMA encoders per antenna are required to handle 12 simultaneous calls. Similarly, in FIG. 11A, four CDMA encoders per antenna are required. Thus, for example, if 180 PN code sequences are available, then 180/6 or 30 CDMA encoders per antenna are required to handle 180 simultaneous calls. If, for these larger number of required accesses, the number of time slots is increased, the number of encoders will decrease proportionally.

ALTERNATE SYSTEM CONFIGURATIONS FIGS. 14, 16

A further enhancement extends the distance between the transfer station diversity antennas by using broadband cables that are a thousand feet or more. The transfer station sends the final radio frequency spread spectrum signal down the cable to the antenna. The antenna at the end of the cable contains a radio frequency amplifier. An implementation distributing signals by cable has the same improvement against blockage as described for the multiple transfer station transmission diversity approach.

However, instead of using a separate cable for each antenna, a preferred embodiment shares a single cable and uses frequency multiplexing to assign a different cable carrier frequency to each antenna. Thus, the desired signal is only transmitted from the antenna nearest to the user which reduces the interference. As a further enhancement, a cable distribution system integrates different elements into a local personal communications system network. The basic building block is the six time slotted CDMA module that serially drives three antennas to obtain triple transmission space and time diversity. For the sake of simplicity, the design of the transfer station handling the incoming TDMA signal also has a basic six time slot structure. The six time slot modularity can readily be deployed to accommodate multiples of 12, 18, 24, and 30 or 32. FIG. 14 shows the implementation for several different combinations. The preferred embodiment utilizes a wireless input, such as W or WE, as the input to the transfer station, however, a cable distribution system works equally well with hard wired signals as the input.

In a cable based personal communication system, the transfer stations are moved back to the central controller, which reduces the cost of the transfer station since it does not have to be ruggedized or remotely powered. It also reduces the number of spares required and the cost to maintain the units since they are all in one place and easy access. The transfer stations can also be dynamically reassigned as the traffic load changes during the day or week, thus significantly reducing the total number of required transfer stations. The bandwidth of the distribution network increases, but developments in cable and fiber optic distribution system have increasing bandwidth at falling cost to accommodate the increase in bandwidth at reasonable cost. The advantage of having several interconnection options to select means that the choice of interconnection becomes an economic choice determined by the cost factors associated with each installation. Each network is expected to include many or all of the interconnection options.

The system arrangement in which the transfer stations are moved back to the same location as the central controller, is depicted in the lower portion of FIG. 14. A general two-way cable or fiber optic wideband distribution system 1402 is used to link the centrally located transfer stations to the remotely located antennas. Considerable flexibility in configuring the wideband spectrum into signal formats is available for linking the centrally located transfer stations to each transfer station antenna. However, for simplicity it is preferable to retain the TDMA protocol with its time slotted CDMA triple space/time diversity air interface protocol, and frequency translate signal as a common air interface to each antenna.

Each antenna is assigned a separate center frequency on the wideband distribution cable 1402. Due to the TDMA and CDMA sharing ability, many users can be served on the same antenna using the same cable frequency. The transfer station antenna at location N, includes a transceiver which is tuned to the assigned cable frequency. The central controller transmits and receives data packets in the final TDMA /CDMA waveform representing telephone traffic on each assigned frequency of the wideband distribution cable 1402. Thus, as shown in FIG. 16, each remote location includes a remote transceiver (transmitter, receiver, local oscillator, diplexer and antenna) at site 1602. The remotely located unit is a relatively simple receiver, frequency translator and low power transmitter, for both the forward and reverse direc-

tions. A low power transmitter amplifier is suitable because the cells are small and triple diversity (three antennas and three time slots) is being used to link the subscriber station to the system. The transmit side of the central controller provides individual information flows along with the associated signaling and control information at interface A' in FIG. 14, which is presented in assignable time slots in the form of packets.

The signaling information includes the called parties identification number(s), code, service profile and authentication code, etc. The control information includes routing information (i.e. which base station, transfer station, antenna designation), power levels, traffic on or off, handoff messages, etc. A large amount of this information is transmitted before the user information (telephone voice traffic) starts passing over the circuit, however, a significant amount of information is also passed during the time when telephone voice traffic is actually on the circuit. A separate control channel is required even after the connection to the user has been completed. The base station function translates this information into the protocol that is required to interface to the TDMA air interface and provides a TDMA radio spectrum at interface W. The transfer station converts the TDMA protocol to a time slotted CDMA triple space/time diversity air interface protocol and transmits this signal first on antenna A, then on antenna B and finally on antenna C (FIG. 14).

The centrally located combined base station and transfer station (B-T) module 1404 combines the base station and transfer station function and converts the signal appearing on A' to the time slotted CDMA triple diversity air interface. A B-T combined module may be achieved by direct combination of separate equipment, or the modules developed for the combined base station and transfer station use can be integrated. The CDMA signal branches at the output of the transfer station or at the output of the B-T module as shown in FIGS. 15 and 16. In the case of the of the transfer stations which are connected to respective antennas by three different cables, the output is just switched at the appropriate time. When one cable is used to reach all the antennas the output of the transfer station is frequency hopped at the appropriate time by changing the synthesizer frequency to the assigned frequency of the antenna. The B-T module is similarly frequency agile.

It is important to note the user information is replicated in each of the three time slots, but the PN code continues to run and is different during each time slot. Therefore, the repetition is not the same as in the case of imitation multipath or emulated multipaths. The PN generator just keeps on running without storing or resetting the sequence. Running the PN code continuously is simpler to implement as compared to starting a PN sequence anew.

In the foregoing discussion, it is assumed the time slots follow one right after the other; this is not necessary, however, as long as the receiver has a priori knowledge of the hopping sequence. In the preferred embodiment, the B-T transmits on two contiguous time slots and then listens to the response signal from the user terminal. During the user transmission time slot the user terminal tells the B-T module to not send the third diversity time slot if the first two time slots have given adequate performance and location measurement is not needed. The use of only dual diversity reduces the interference to the other users, and frees up the user receiver to perform other functions.

An alternate approach is to utilize a ⅓ forward error correcting code that is spread over all three time slots. The use of such coding provides improved performance if the error statistics during each of the time slots are nearly the same. If one time slot becomes significantly worse, and it can be identified as being bad, it may be better to ignore the bad time slot and request an antenna handoff to replace that time slot if the poor performance continues. Since it is expected that the real diversity channel statistics will result in unequal time slot statistics, the preferred alternative is to not use a forward error correcting code over the three time slots. Even though error detecting and correcting codes are only included within each time slot, forward error correcting codes may be used over multiple time slots.

Each antenna, assuming there is data to transmit, transmits during each of the time slots. Since the data is transmitted three times there will be three CDMA signals transmitted in each time slot for each module assigned to that antenna. If there are 4 modules assigned to the antenna, 4 modules supports 24 users at any one time, there would be 12 CDMA signals emanating from the antenna in each time slot, (see FIG. 11A, 11B). If the duty factor is approximately 50% then only six CDMA signals will actually be transmitting and if 20 to 25% of the time the third time slot is not required only 4 to 5 CDMA signals would be transmitted at a time. The same antennas are used for the receive side, or reverse link, (user to transfer station).

As stated previously the user CDMA terminal transmits only during one time slot and the transfer station simultaneously receives that transmission on the same three antennas resulting in receiver triple space diversity. The three receive signals come into the transfer station, or B-T module, either on separate wires or at different frequencies, as shown in FIG. 15 and 16, and are processed separately. These processed signals are summed together using maximum likelihood combiners. The S/I from each antenna path is measured and kept in memory over an interval of at least ten time slots. The record of signal statistics is used by the maximum likelihood combining process. Stored signal statistics are also useful in the decision process for executing handoff to other antennas.

The handoff process for the B-T cable network is based on the signal received from each of the antennas. The central processor receives information on the quality of the links in both directions. On the forward link it receives information from the user CDMA receiver operating on that link during an assigned time slot which is identified with a particular antenna. On the reverse link it receives information on the separate paths through different antennas. The information on the quality of paths through a particular antenna can be evaluated and compared to other current paths through different antennas and with other new paths that the user terminal is continuously searching. When a current path in a particular time slot continues to deteriorate and a better path is available the central controller assigns a new path (antenna) to the user terminal and notifies the user terminal it has done so.

The handoff process for the transfer station is similar except the handoff is generally between transfer stations rather than antennas. When handed off from transfer station to transfer station all three antennas associated with a particular transfer station are handed off with the transfer station. A few transfer stations may be implemented with widely separated antennas. In the case where there are transfer stations with widely separated antennas the handoff process described for B-T module could also be used.

Operational Description: A new subscriber turns on his CDMA user terminal and scans the synchronization codes

until he acquires a synchronization code. The CDMA user terminal then initiates a registration message. The transfer station receives this message and passes it to the central controller who acknowledges it with an acknowledgment message back to the user terminal. The central controller goes to the home register of the new terminal and obtains the user profile and places it in the file for active users. The new user is now registered and all calls will be forwarded to this new region of service.

There are 28 different synchronization codes and one synchronization code is assigned to each area. The 28 areas make up a region and the codes are repeated in the next region. The transfer stations within an area are given different shifts or starting points for their particular code. Therefore, each transfer station, or widely separated antenna, has an identifiable code. The central controller knows which antenna, or transfer station, that the new user registered through so the controller will route all information to the new user through that node. The central controller will also give the new user a set of codes, or different starting points on his current code, to search for the purpose of identifying diversity paths or handoff candidates. The new user continues to monitor the synchronization and control channel during half his time slots. The other half of his time slots he scans for better synchronization channels.

The user is paged on the control channel and given a CDMA and time slot assignment which he sets up so he will be ready for the beginning of the call. When the user requests service he is also given a CDMA code and time slot assignment for the duration of the call. The user terminal remains in this state until the end of the call, unless the signal in one or all the diversity paths becomes weak. Since the user receiver is continuously evaluating the incoming signals and scanning for better new paths, it will know if a path is going bad and will notify the central controller of this condition along with a list of better candidates. The central controller will order a handoff and the user terminal will go to the new CDMA code and time slot. None of this activity is detectable by the end user.

At the beginning of each time slot is a short unmodulated section, without user information, used for resynchronization and range adjustment, followed by a short control message section. These short bursts are sent whether there is user information to be sent or not. If no user information is to be sent the control message confirms this and the transmitter power is reduced by ten db. for the user information portion of the time slot. It should be noted four time slots are available on the forward channel for passing user information depending on what agreements have been established between the user and the central controller. These slots as described above can be turned off so that other users have access to additional capacity. The multiple time slots can be used for diversity improvement or sending increased data rates, multiple data channels or a graphics channel along with a voice channel. The possibility of extending several parties on a conference call is also possible.

LOCATION PROCESSING FIGS. 20, 21, 22, 23

FIG. 20 shows the radio links of FIG. 1 or FIG. 4, where the car and its antenna are represented by user antenna U. The radio links are time slotted as shown in FIG. 10A. The radio link AU is time slotted and is present during time slot 1. Radio link BU is also time slotted and is present during time slot 2. Radio link CU is also time slotted and is present during time slot 4. Radio link AU establishes the absolute range from U to antenna A. The range to antenna A forms a reference to measure the difference in path lengths between radio links AU and BU. Similarly, the path length of radio link AU is also used as a reference to measure the difference in path lengths between radio links AU and CU.

Since the time occurrence of the all ones vector (for synchronization) is the same at all three antennas, the ranges to all three antennas may be derived from the difference in respective arrival times of the all ones vector within each time slot. The location center, having the physical geographic coordinates of all three antennas, calculates the location of the users antenna U.

The geometry of location determination is shown in FIGS. 20, 21, 22 and 23. The first range measurement AU establishes the user as someplace on circle A in FIG. 21. The second range determination establishes the user as also being someplace on circle B. The only locations this can be true is where the circles intersect each other at points X and Z. Therefore, his location has been narrowed down to two possible points. The third range determination establishes the user someplace on circle C. Since the user is also on circle C, he must be at point Z. Obtaining additional ranges to other antennas confirms the first set of measurements and in many cases improves on the accuracy. If the terrain has significant variations in height the constant range circles become constant range spheres and the extra measurements remove any ambiguity that could be caused by adding the third dimension. The position location processing center converts these coordinates into user friendly instructions. Range measurements by the CDMA system are obtained as follows:

1. The pseudo noise code as it is stretched out between A and U to act as a yardstick. The time required to propagate between A and U allows many chips, the propagation time in microseconds times the chip rate in megachips, to represent the length of the link or be "stored" in the link during signal propagation. See FIG. 20.

2. There are two ways to increase the number of chips stored in the propagation path. One is to increase the path length and the other is to speed up the chip clock rate. Increasing the chip clock rate is analogous to marking a ruler in a smaller scale. Therefore, increasing the chip clock rate stores more chips in the path delay and makes it possible to make more accurate measurements.

3. The path length from antenna A to user terminal U and back to antenna A, can be measured by transmitting from A, then retransmitting the same PN code, with the arriving phase, from user terminal U, and comparing the repeated signal as it is received back at antenna A to the signal that was previously transmitted from antenna A. By delaying the original signal until it matches, chip by chip, the received signal, at A, and counting the number of chips that are slipped, the total delay is proportional to twice the distance between antenna A and antenna U.

4. The accuracy of the distance measurement is approximately ¼ of the number of feet represented by one chip. The ¼ chip is an implementation constraint determined by how precisely the correlation peak is detected and tracked. It is possible to reduce this error by autocorrelation techniques, but ¼ chip is a realistic resolution.

5. To determine the path length between antenna A and user terminal U, described in paragraph 3 above, FIG. 22 shows the signals 2202 transmitted and signals 2204 received at antenna A. At a chip clock rate of 10 megachips per second, there are approximately 100 feet represented by each chip. The delay of 51 chips between transmitted 2202

and received 2204 signals represents the time required for a radio wave to traverse a round trip between the subscriber station and the transfer station. One half of the round trip delay, or 25.5 chips represents the distance to the antenna. Thus, the distance from antenna A to user terminal antenna U for the example in FIG. 22 is (51×100)/2=2550 feet. The distance measurement accuracy is plus or minus 25 feet (100 feet/4).

6. Thus, the distance AU is measured quite precisely. As described previously the receiver uses a single receiver for all time slots. While the subscriber receiver is listening to time slot one it is working in conjunction with the base station, to repeat the received waveform, same phase with no delay through the user terminal. The base station receiver, as described above, compares the received phase with the transmitted phase to determine absolute range. The base station then transmits the range value, thus measured, to the user terminal where it is stored for future retrieval and use. As noted above it is the waveform phase that is important, if the starting point, the all ones vector, is maintained through the user terminal, a new similar PN code may be substituted on the reverse link. A similar code could include that same code shifted by a defined offset.

7. The same forward and return measurement process described above, could be used to obtain the other two ranges (to antennas B and C) with the results also stored in memory at the user station. However, direct range measurement to all three antennas is not necessary. See FIG. 23. The same receiver retrieves information over all three paths. In so doing, the receiver adjusts for the difference in path length at the beginning of each time slot. Once the adjustment is accomplished, on the first time the receiver uses this antenna as an information channel, the code is stored and retained in memory until the radio returns to this time slot whereupon, it is taken from the memory and used as the starting point for the tracking loops. Therefore, the receiver is essentially maintaining three separate sets of receiver parameters, emulating three different receivers, one set of parameters for time slot 1, a different set for time slot 2 and still a different set for time slot 3. The distances to antenna B and antenna C can be determined by adding or subtracting the offset, measured in chips, from the absolute range value measured on link AU. Actually the offset is determined before the time slot is used for the first time as an information channel, this determination is made in the process of looking for new paths for handoff. The delay and measure of signal quality is determined and maintained in the potential handoff targets file. These delay offset measurements are also used as additional range measurements in the position location process.

In particular, continuing the above example, the signal 2302 transmitted at antenna A represents a range of 25.5 chips from antenna A to user terminal antenna U. Signal 2304 received at antenna U from antenna A is used as a reference to measure the relative time of arrival of signals from antennas B and C, adjusted for the different time slots in which these signals are placed.

Since timing for time slots 1, 2 and 3 is sequential, the real time chip patterns for slots 2 and 3 do not overlap. However, after adjustment for time slot delays, the timing relationship is as shown in FIG. 23. Thus adjusted for the time slot difference, signal 2306 received from antenna B at user terminal antenna U, is received in advance (i.e., offset relative to the signal from antenna A) by 8 chips. Similarly, signal 2308 received from antenna C at user terminal U, is also received in advance (i.e., offset relative to the signal from antenna C), but by 6 chips. Received signals may be either delayed or advanced (i.e., have a positive or negative delay) relative to the reference signal 2304. Receipt in advance indicates that the antenna (B or C) is closer than antenna A. Conversely, a delayed receipt indicates that the antenna (B or C) is further away than antenna A.

In FIG. 23, the range from antenna B to antenna U is 25.5−8=17.5 chips. In feet, 17.5 chips is 17.5×100=1750 feet, the length of path BU. The range from antenna C to antenna U is 25.5−6=19.5 chips. In feet, 19.5 chips is 19.5×100=1950=path length CU. The user terminal may be located at Z, the intersection of circle A at 2250 feet from antenna A, circle B at 1750 feet from antenna B and circle C at 1950 feet from antenna C.

In the alternative, location measurement may be accomplished by computing the intersection of two hyperbolas. The first hyperbola is the locus of all points having a fixed difference in distance from two foci, which is proportional to the difference in delay between antenna A and antenna B. The second hyperbola is the locus of all points having a fixed difference in distance from two foci, which is proportional to the difference in delay between antenna B and antenna C, (or antenna A and antenna C). Antennas A and B are the foci of the first hyperbola, while antennas B and C are the foci of the second hyperbola. In such manner, subscriber location may be computed without requiring a two way exchange between the user terminal and the transfer station to establish a first range measurement.

LOCATION SERVICES FIGS. 18, 19

Since, the subscriber station receiver is receiving information over three different paths that emanate from known locations, position location information is derived by measuring the time of arrival of messages relative to a fixed time reference. The measurement accuracy depends on the chip rate, but at a chip rate of 10 megachips per second it is quite accurate. There are several ways location measurement and display can be accomplished, depending on how much processing is available in the user terminal. The choice also depends on who will actually use the information. It could be fairly passive, using only the relative chip offset information and obtaining a reference from the current cell. The user could locally derive and display his location, similar to using a GPS satellite. A GPS receiver displays longitude and latitude reading. Location information may also be sent back to a processing center that provides a service to the user. The processing center converts the longitude and latitude coordinates into a location having geographic meaning, such as, a block number on a specific street.

Local geographic position measurement is particularly attractive to people concerned about security and health problems. The manager of the service center could either notify the police, family designate or the service center could include, as part of a special service rate, the staff to check on irregular circumstances. Of course, the service center can also, for a nominal fee, tell an individual his street location and give instructions on how to get to a desired destination address. These services can be provided to users who are pedestrians or moving along in vehicles. The destination instructions can be in the form of a set of one time detailed directions, or specific and continuous intersection prompting as the user travels the suggested route. The prompting could take the form of a voice command, or text display, telling the user to turn right at the next intersection. A delivery truck, cab, ambulance or fire truck could have a special screen that showed a local map with instructions

written on it. The instructions can also be modified as the traffic congestion changes. The benefits of the present system are a significant increase in public safety, convenience and productivity.

In the system configurations described previously, the separation between antennas is made sufficient to yield an accurate position location capability. By positioning the antennas to obtain independent paths sufficient to avoid flat fading due to interfering obstacles, then the separation is also sufficient to reduce the triangulation error to a very small number. The incremental cost of including optimization for a location capability is nominal.

Position location processing is accomplished by a third party provider which owns and manages the position location center. Location service can be accomplished in several ways. The preferred approach is to make the user terminal the repository for all location information by building and maintaining a location file. The position location center queries the user terminal over the normal public switched telephone network (preferably packet) when it needed information. Preferably, a provision for encryption during transmission and an access code for privacy is used. The user terminal could also send location information to the location center, also over the public switched telephone network, responsive to user activation. For instance, when the user pushed an alarm button, the radio sends the alarm message, along with the location information, to the location center. The location center would respond according to prearranged directions and the level of subscribed service. Since the user terminal radio develops the code offset information internally, the only additional information the cellular system needs to provide to the user terminal is the distance, one way or round trip, from the user to one of the base station/antennas. The distance information, which would be provided as a service feature to the user, must identify the base station/antenna. All the measurements must be performed within a time window of 100 milliseconds or the error as a result of vehicle movement between measurements could become excessive. For stopped vehicles or pedestrians the time window to perform location measurements could be much longer since there is little or no movement between measurements. Therefore, the distance measurement sent by the system to the user terminal includes the distance in feet, the time in milliseconds and the identity of the measuring entity. Upon receipt of the distance message the user terminal stores the message and makes code offset measurements to several different antennas, and, if signal levels are adequate, stores the composite information in the location file. The location file is retained until a new distance message is received by the user terminal radio, whereupon the user terminal radio again makes the code offset measurements and updates the location file.

When the location center queries the user terminal radio as to its location, the radio sends the contents of the location file. The location center processes this data into very accurate map data, position on a particular street (can be displayed on a typical street map) The system measures distance to the subscriber normally once every minute when the subscriber is in the active receive mode, receiver on, waiting to be paged. The period between measurements is variable and can be adjusted according to the needs of the user. The system sends this new distance to the subscriber station which places it in the file and enters new code offset measurements with it. If the subscriber is engaged in a conversation, the user terminal is transmitting, the base station makes a measurement every ten seconds and if the distance changes more than one hundred feet the system

sends a message to the subscriber station. Whenever the user terminal receives a distance measurement it adds the local code offset measurements and updates the file.

It can be seen the user terminals location file is updated at least every minute and more often if warranted. Therefore, the system can know the location of any active user within a distance of approximately 100 feet. Better accuracy and more frequent updating is certainly possible, but due to the loading on the data links the number of subscribers receiving higher performance should be the exception rather than the rule. Whenever the user presses the alarm button on his portable terminal, the terminal transmits the contents of the location file three times which is long enough for the system to read a new distance and send a message to the user terminal. The user terminal makes several offset measurements and sends the new location file three times. The alarm message is repeated every thirty seconds until the battery goes dead. The user terminal radio can have a module added (with its own battery) that emits an audible tone whenever the radio alarm message is transmitted.

The system generates raw location information at the user terminal that needs to be converted into human readable map data. In general, the basic longitude, latitude, or angle and distance readings are fine. However, there is a need for a third party to translate this data into a format that is quickly usable by the mass public, as a service business. Since the user terminal has the basic location information, it can be provided to any authorized entity that requests it from the user terminal. The location processing center periodically queries the subscribed user terminals and maintain a file on their current location. One potential service for subscribers with health problems, is a monitoring system during exercise. If the subscriber stops in an unusual location for an excessive length of time and does not press the alarm button, the location center operator could request life signs or send a medical technician to the paused subscriber. If there is an emergency, the location center operator knows the subscriber location in order to send help. On the other hand, when the alarm button is pressed, the alarm message is addressed to the location center where they are equipped to handle such emergencies. The capability to track user terminals and provide help as the result of some action is useful for many applications. Tracking stolen cars, identifying congestion, keeping ambulances from getting lost and reporting vandalism are but a few examples of the application of the present invention.

The system does, particularly in its distributed configuration as described previously, require a consistent zero time reference across the different base station antennas. Having a zero time reference available significantly reduces the time to resynchronize as the signal hops from antenna to antenna and also aids in the search and handoff process. The location application capability described above allows the system to periodically perform a self calibration by placing several of the user terminals, as described above, at fixed locations and determining the proper zero time setting for these locations. By keeping the correct answer in the central processor, as the system scans these check points, it will get an error indication if the system is out of calibration. The same check points are used to show the effective delay, during the process wherein a variable delay is introduced by incrementing or decrementing the system delay in one or more of the signal paths in the recalibration or adjustment process.

The calibration process could be easily automated. Automation could be implemented in two ways. The first approach is to scan the check points every minute and determine any error that has developed. If this error reaches

a significant level the communication system contacts the location center and provides the center with the corrections that need to be factored into the position location calculations. The latter approach requires close coordination between the communication system and the position location center. A more autonomous approach would be desirable. The communication system itself could maintain the proper "zero" state by scanning the check points, as described above, and by having the ability to insert or remove delay **1806** in the path to the antenna.

FIG. **18** illustrates a system with self-calibration. Once every minute the system queries each check point **1802**. This results in a distance measure being sent to the check point **1802** where the check point receiver adds the code offset measurements and sends the contents of the location file to the processor **1804** where the received file is compared with a file that contains the correct measurements. If the difference exceeds the threshold the processor **1804** calculates the changes in delay that are required to bring the measurements within tolerance and passes the correction to the controller. The controller maintains a file that includes the variable delay **1806** to be inserted for each antenna. The controller changes the delay entry in the file and a new measurement is taken to validate the calibration. Changes that require significant changes in delay are unlikely, but if this should happen the controller would not initiate any measurements that include the leg that is under recalibration. Thus, the position location capability also provides a service for the communication system. Self calibration results in a significant reduction in installation cost and allows the use of more economical system components.

Location related communications between the antenna devices and the subscriber terminal can be broken into several different links. The functions that are performed by these different links are: 1, distance measurement (requires a two way link, but no traffic); 2, sending measurement information to subscriber terminal (one way data link, except for possible retransmission requests); 3, measuring code offset (only requires user terminal to listen, no data is transferred); 4, Transmit location file to location center or communication processor **1804** (data links can be either one way or two way). Distance measurement can only be performed by the system and since it requires a two way link it can be done while a normal conversation channel has been established or if the terminal is in the listening mode the system has to establish a short round trip connection.

The two way link is required because the base station measures the code phase difference between the signal it sends to, and the signal it receives from, the user terminal. In FIG. **18** the foregoing function is accomplished in processor **1804**. In this sense, the system operates like a radar with a pulse the width of a PN chip. The one way data link message transporting the distance message to the user terminal, is a single message that typically will include an error correcting code, and may also require an acknowledgment message to be sent back from the user terminal to the base station. The acknowledgment message could be sent independently or appended as part of the distance measurement function.

The code offset information is also placed it in a file that is accessible from outside the system. As described previously the user terminal time shares one receiver on the three independent paths that emanate at different times from the three different antennas. Therefore, the receiver tracks three independent paths one after the other. The PN code on each path is the same, and as described above the code has the same starting time at each antenna, but because of the difference in distance to the three different antennas, from the user terminal, the codes arriving at the user terminal are of different code phases. However, since the system cycles very rapidly from antenna to antenna, the receiver cycles between signals received from each of the antennas. Therefore, the receiver maintains three separate starting states and tracking loops for the different time slots. At the end of each time slot, the exact time is known in advance, the previous state is stored in the computer and restored at the beginning of the next time slot assigned to the same antenna. Thus, the processor is emulating three different receivers. The receiver quickly adjusts for any slight drift that occurred while the receiver was locked to the other antennas. Note that the receiver has a specific starting state. Thus, the PN sequence has been shifted to compensate for the difference in range on the path between the user terminal and the first antenna and the path between the user terminal and the second antenna. The difference is the code offset, because the code offset measures the difference in range. Thus, the distance to the second antenna is known without having to do a closed loop (two way) measurement. The same process is followed for the third antenna.

Additional entries, greater than three, in the location file are available using the normal search mode that the user terminal radio uses to identify potential candidates for handoff. The user terminal radio searches the pilot codes emanating from nearby antennas to determine if any of these antennas have better signals than one of the three that are currently being used. If so, the user terminal notifies the system that a good candidate is available. The process of searching starts at the state of the PN signal coming in from time slot number one and if nothing is found at that state the radio adds a chip to the path length and integrates again. The radio keeps adding chips until it finds a signal or exceeds a range threshold. If it exceeds the range threshold it resets the PN generator to a new pilot code and starts at the 0 offset distance again. Therefore, when the radio finds a new pilot signal it knows how many chips it added before it was successful. The added number of chips is also the code offset. The code offset value along with the identity of the code, which uniquely names the antenna, and the time stamp are entered into the location file. The radio places these entries in the location file even if they are not better than the current signals. As the radio scans and finds new antennas it places the four best results in the location file. As it continues to scan, older entries are replaced with newer better entries.

Now that the necessary information is available in the user terminal location file, it may be made available to any authorized requester. Location services may be provided by the communications operator or by a competitive independent service provider. In addition, there will also be large private location centers operated by owners of large fleets. The location center **1902** receives the location files over the public switched network, see FIG. **19**. The network can be a circuit switched network or a packet switched network. A packet switched network is adequate and economical for this type of application.

What is claimed is:

1. In a wireless communication system, wherein a data packet is communicated from a transmitter to a receiver to form a received data packet, a method for determining the location of said receiver, said system including first, second and third antennas spaced apart from each other, said method comprising:

transmitting said data packet from said first antenna to form a first transmitted data packet;

transmitting said data packet from said second antenna to form a second transmitted data packet after said first transmitted data packet;

transmitting said data packet from said third antenna to form a third transmitted data packet after said second transmitted data packet;

receiving in sequence said first, second and third transmitted data packets at said receiver forming respective first, second and third received data packets;

selecting at least one of said first and second received data packets to form said digital data at said receiver;

measuring the respective time of arrival of said first, second and third transmitted data packets at said receiver; and

computing the location of said receiver from said respective measured time of arrival of said first, second and third transmitted data packets.

2. A wireless communication system in accordance with claim 1, wherein said step of computing the location of said receiver from said respective measured time of arrival of said first, second and third transmitted data packets comprises computing the distance to at least one of said first, second and third antennas.

3. A wireless communication system in accordance with claim 1, wherein said step of computing the location of said receiver from said respective measured time of arrival of said first, second and third transmitted data packets comprises computing the difference in distance between said receiver to said first and second antennas.

4. A wireless communication system in accordance with claim 3, wherein said step of computing the location of said receiver from said respective measured time of arrival of said first, second and third transmitted data packets comprises computing the difference in distance between said receiver to said second and third antennas.

5. A wireless communication system in accordance with claim 1, wherein said step of computing the location of said receiver from said respective measured time of arrival of said first, second and third transmitted data packets comprises computing a first distance to said first antenna, computing a second distance to said second antenna and computing a third distance to said third antenna, and calculating the position of said receiver as the intersection of three constant distance curves from said respective first, second and third antennas at said respective first, second and third distances.

6. In a wireless communication system, wherein a data packet is communicated from a base station to a subscriber station using a CDMA PN sequence, said system including at least one transfer station between said base station and said subscriber station for receiving said data packet from said base station and retransmitting said data packet using said PN sequence to said subscriber station on a first antenna to form a first transmitted data packet and retransmitting said data packet using said PN sequence on a second antenna to form a second transmitted data packet after said first transmitted data packet, a method in a receiver in said subscriber station for receiving said data packet, said method comprising:

receiving said first transmitted data packet at said subscriber station receiver forming said first received data packet;

receiving said second transmitted data packet at said subscriber station receiver forming respective second received data packet after receiving said first transmitted data packet;

wherein said system further includes retransmitting said data packet using said PN sequence on a third antenna to form a third transmitted data packet after said second transmitted data packet, said method for receiving said data packet in said subscriber station receiver further comprising:

receiving said third transmitted data packet at said subscriber station receiver forming said third received data packet after receiving said second transmitted data packet;

selecting at least one of said first, second and third received data packets to form said received data packet at said receiver;

measuring the respective time of arrival using said PN sequence phase relative to said first, second and third transmitted data packets at said subscriber station, and

computing and subsequently storing in said subscriber station the location of said subscriber station from said respective measured time of arrival of said first, second and third transmitted data packets.

7. A wireless communication system in accordance with claim 6, wherein said step of computing the location of said subscriber station from said respective measured time of arrival of said first, second and third transmitted data packets comprises computing the distance to at least one of said first, second and third antennas.

8. A wireless communication system in accordance with claim 6, wherein said step of computing the location of said subscriber station from said respective measured time of arrival of said first, second and third transmitted data packets comprises computing the difference in distance between said receiver to said first and second antennas.

9. A wireless communication system in accordance with claim 8, wherein said step of computing the location of said subscriber station from said respective measured time of arrival of said first, second and third transmitted data packets comprises computing the difference in distance between said receiver to said second and third antennas.

10. A wireless communication system in accordance with claim 6, wherein said step of computing the location of said subscriber station from said respective measured time of arrival of said first, second and third transmitted data packets comprises computing a first distance to said first antenna, computing a second distance to said second antenna and computing a third distance to said third antenna, and calculating the position of said receiver as the intersection of three constant distance curves from said respective first, second and third antennas at said respective first, second and third distances.

11. A method in accordance with claim 6, further comprising transmitting a location file containing data representing said location of said subscriber station from said subscriber station to said base station.

12. In a wireless communication system, wherein a data packet is communicated from a base station to a subscriber station using a CDMA PN sequence, said system including at least one transfer station between said base station and said subscriber station for receiving said data packet from said base station and retransmitting said data packet using said PN sequence to said subscriber station on a first antenna to form a first transmitted data packet and retransmitting said data packet using said PN sequence on a second antenna to form a second transmitted data packet after said first transmitted data packet, a method in a receiver in said subscriber station for receiving said data packet, said method comprising:

receiving said first transmitted data packet at said subscriber station receiver forming said first received data packet;

receiving said second transmitted data packet at said subscriber station receiver forming respective second received data packet after receiving said first transmitted data packet;

wherein said system further includes retransmitting said data packet using said PN sequence on a third antenna to form a third transmitted data packet after said second transmitted data packet, said method for receiving said data packet in said subscriber station receiver further comprising:

receiving said third transmitted data packet at said subscriber station receiver forming said third received data packet after receiving said second transmitted data packet;

selecting at least one of said first, second and third received data packets to form said received data packet at said receiver;

measuring the respective time of arrival using said PN sequence phase relative to said first, second and third transmitted data packets at said subscriber station;

computing a location file comprising data representing the location of said subscriber station from said respective measured time of arrival of said first, second and third transmitted data packets; and

transmitting the contents of said location file containing data corresponding to said measured respective time of arrival of said first, second and third transmitted data packets at said subscriber station from said subscriber station to said base station.

13. A method in accordance with claim **12**, wherein said base station receives the contents of said location file containing data corresponding to said measured respective time of arrival of said first, second and third transmitted data packets at said subscriber station, computes the location of said subscriber station, and transmits the computed location of said subscriber station to said subscriber station, said subscriber station method further comprising the step of receiving said computed subscriber station location.

14. A method in accordance with claim **12**, wherein said location file contains data representing the distance to one of said first, second and third antennas, and the respective differences in time of arrival of received data packets between said one of said first, second and third antennas, and the remaining two other ones of said first, second and third antennas.

15. A method in accordance with claim **12**, wherein said location file data is accessed by said base station by dial up through the public switched telephone network.

16. A method in accordance with claim **12**, wherein said location file data is accessed by a password and transmitted to said base station in encrypted form.

17. A method in accordance with claim **12**, wherein said location file data is transmitted to said base station responsive to an initiation indication at said subscriber station.

18. A method in accordance with claim **12**, wherein said location file data is accessed by a password.

19. A method in accordance with claim **12**, wherein said location file data is transmitted to said base station in encrypted form.

20. A method in accordance with claim **12**, further comprising transmitting a location file containing data representing said location of said subscriber station from said subscriber station to a location service center separate from said base station.

21. In a wireless communication system, wherein a data packet is communicated from a transmitter to a receiver to form a received data packet, an apparatus for determining the location of said receiver, said system including first, second and third antennas spaced apart from each other, said apparatus comprising:

means for transmitting said data packet from said first antenna to form a first transmitted data packet;

means for transmitting said data packet from said second antenna to form a second transmitted data packet after said first transmitted data packet;

means for transmitting said data packet from said third antenna to form a third transmitted data packet after said second transmitted data packet;

means for receiving in sequence said first, second and third transmitted data packets at said receiver forming respective first, second and third received data packets;

means for selecting at least one of said first and second received data packets to form said digital data at said receiver;

means for measuring the respective time of arrival of said first, second and third transmitted data packets at said receiver; and

means for computing the location of said receiver from said respective measured time of arrival of said first, second and third transmitted data packets.

22. A wireless communication system in accordance with claim **21**, wherein said means for computing the location of said receiver from said respective measured time of arrival of said first, second and third transmitted data packets comprises computing the distance to at least one of said first, second and third antennas.

23. A wireless communication system in accordance with claim **21**, wherein said means for computing the location of said receiver from said respective measured time of arrival of said first, second and third transmitted data packets comprises means for computing the difference in distance between said receiver to said first and second antennas.

24. A wireless communication system in accordance with claim **23**, wherein said means for computing the location of said receiver from said respective measured time of arrival of said first, second and third transmitted data packets comprises means for computing the difference in distance between said receiver to said second and third antennas.

25. A wireless communication system in accordance with claim **21**, wherein said means for computing the location of said receiver from said respective measured time of arrival of said first, second and third transmitted data packets comprises means for computing a first distance to said first antenna, means for computing a second distance to said second antenna and computing a third distance to said third antenna, and means for calculating the position of said receiver as the intersection of three constant distance curves from said respective first, second and third antennas at said respective first, second and third distances.

26. In a wireless communication system, wherein a data packet is communicated from a base station to a subscriber station using a CDMA PN sequence, said system including at least one transfer station between said base station and said subscriber station for receiving said data packet from said base station and retransmitting said data packet using said PN sequence to said subscriber station on a first antenna to form a first transmitted data packet and retransmitting said data packet using said PN sequence on a second antenna to form a second transmitted data packet after said first transmitted data packet, an apparatus in a receiver in said subscriber station for receiving said data packet, said apparatus comprising:

means for receiving said first transmitted data packet at said subscriber station receiver forming said first received data packet;

means for receiving said second transmitted data packet at said subscriber station receiver forming respective second received data packet after receiving said first transmitted data packet,

wherein said system further includes retransmitting said data packet using said PN sequence on a third antenna to form a third transmitted data packet after said second transmitted data packet, said apparatus for receiving said data packet in said subscriber station receiver further comprising:

means for receiving said third transmitted data packet at said subscriber station receiver forming said third received data packet after receiving said second transmitted data packet; means for selecting at least one of said first, second and third received data packets to form said received data packet at said receiver;

means for measuring the respective time of arrival using said PN sequence phase relative to said first, second and third transmitted data packets at said subscriber station, and

means for computing and subsequently storing in said subscriber station the location of said subscriber station from said respective measured time of arrival of said first, second and third transmitted data packets.

27. A wireless communication system in accordance with claim 26, wherein said means for computing the location of said subscriber station from said respective measured time of arrival of said first, second and third transmitted data packets comprises computing the distance to at least one of said first, second and third antennas.

28. A wireless communication system in accordance with claim 26, wherein said means for computing the location of said subscriber station from said respective measured time of arrival of said first, second and third transmitted data packets comprises means for computing the difference in distance between said receiver to said first and second antennas.

29. A wireless communication system in accordance with claim 28, wherein said means for computing the location of said subscriber station from said respective measured time of arrival of said first, second and third transmitted data packets comprises means for computing the difference in distance between said receiver to said second and third antennas.

30. A wireless communication system in accordance with claim 26, wherein said means for computing the location of said subscriber station from said respective measured time of arrival of said first, second and third transmitted data packets comprises means for computing a first distance to said first antenna, means for computing a second distance to said second antenna and means for computing a third distance to said third antenna, and means for calculating the position of said receiver as the intersection of three constant distance curves from said respective first, second and third antennas at said respective first, second and third distances.

31. An apparatus in accordance with claim 26, further comprising means for transmitting a location file containing data representing said location of said subscriber station from said subscriber station to said base station.

32. In a wireless communication system, wherein a data packet is communicated from a base station to a subscriber station using a cdma PN sequence, said system including at least one transfer station between said base station and said subscriber station for receiving said data packet from said base station and retransmitting said data packet using said PN sequence to said subscriber station on a first antenna to form a first transmitted data packet and retransmitting said data packet using said PN sequence on a second antenna to form a second transmitted data packet after said first transmitted data packet, an apparatus in a receiver in said subscriber station for receiving said data packet, said apparatus comprising:

means for receiving said first transmitted data packet at said subscriber station receiver forming said first received data packet;

means for receiving said second transmitted data packet at said subscriber station receiver forming respective second received data packet after receiving said first transmitted data packet;

wherein said system further includes means for retransmitting said data packet using said PN sequence on a third antenna to form a third transmitted data packet after said second transmitted data packet, said apparatus for receiving said data packet in said subscriber station receiver further comprising:

means for receiving said third transmitted data packet at said subscriber station receiver forming said third received data packet after receiving said second transmitted data packet;

means for selecting at least one of said first, second and third received data packets to form said received data packet at said receiver;

means for measuring the respective time of arrival using said PN sequence phase relative to said first, second and third transmitted data packets at said subscriber station;

means for computing a location file comprising data representing the location of said subscriber station from said respective measured time of arrival of said first, second and third transmitted data packets; and

means for transmitting the contents of said location file containing data corresponding to said measured respective time of arrival of said first, second and third transmitted data packets at said subscriber station from said subscriber station to said base station.

33. An apparatus in accordance with claim 32, wherein said base station receives the contents of said location file containing data corresponding to said measured respective time of arrival of said first, second and third transmitted data packets at said subscriber station, computes the location of said subscriber station, and transmits the computed location of said subscriber station to said subscriber station, said subscriber station apparatus further comprising the means for receiving said computed subscriber station location.

34. An apparatus in accordance with claim 32, wherein said location file contains data representing the distance to one of said first, second and third antennas, and the respective differences in time of arrival of received data packets between said one of said first, second and third antennas, and the remaining two other ones of said first, second and third antennas.

35. An apparatus in accordance with claim 32, wherein said location file data is accessed by said base station by dial up through the public switched telephone network.

36. An apparatus in accordance with claim 32, wherein said location file data is accessed by a password and transmitted to said base station in encrypted form.

37. An apparatus in accordance with claim 32, wherein said location file data is transmitted to said base station

responsive to an initiation indication at said subscriber station.

38. An apparatus in accordance with claim 32, wherein said location file data is accessed by a password.

39. An apparatus in accordance with claim 32, wherein said location file data is transmitted to said base station in encrypted form.

40. An apparatus in accordance with claim 32, further comprising means for transmitting a location file containing data representing said location of said subscriber station from said subscriber station to a location service center separate from said base station.

41. In a wireless communication system, wherein a data packet is communicated from a transmitter to a receiver to form a received data packet, including a method for determining the location of said receiver, said system including first, second and third antennas spaced apart from each other, a method for calibrating said location system, said calibration method comprising:

positioning a calibration receiver at a known location;

transmitting said data packet from said first antenna to form a first transmitted data packet;

transmitting said data packet from said second antenna to form a second transmitted data packet after said first transmitted data packet;

transmitting said data packet from said third antenna to form a third transmitted data packet after said second transmitted data packet;

receiving in sequence said first, second and third transmitted data packets at said calibration receiver forming respective first, second and third received data packets;

measuring the respective time of arrival of said first, second and third transmitted data packets at said calibration receiver;

computing the location of said calibration receiver from said respective measured time of arrival of said first, second and third transmitted data packets; and

comparing the computed location of said calibration receiver to said known location.

42. A wireless communication system in accordance with claim 41, wherein said calibration method further comprises computing the difference between said computed location and said known location, and introducing respective delays in transmissions from said first, second and third antennas to calibrate said system.

43. A wireless communication system in accordance with claim 41, wherein said calibration method further comprises computing error indications representing the difference between said computed location and said known location, and storing said error indications for use in said method for determining the location of said receiver to calibrate said system.

44. In a wireless communication system, wherein a data packet is communicated from a transmitter to a receiver to form a received data packet, including an apparatus for determining the location of said receiver, said system including first, second and third antennas spaced apart from each other, an apparatus for calibrating said location system, said calibration apparatus comprising:

a calibration receiver positioned at a known location;

means for transmitting said data packet from said first antenna to form a first transmitted data packet;

means for transmitting said data packet from said second antenna to form a second transmitted data packet after said first transmitted data packet;

means for transmitting said data packet from said third antenna to form a third transmitted data packet after said second transmitted data packet;

means for receiving in sequence said first, second and third transmitted data packets at said calibration receiver forming respective first, second and third received data packets;

means for measuring the respective time of arrival of said first, second and third transmitted data packets at said calibration receiver;

means for computing the location of said calibration receiver from said respective measured time of arrival of said first, second and third transmitted data packets; and

means for comparing the computed location of said calibration receiver to said known location.

45. A wireless communication system in accordance with claim 44, wherein said calibration means further comprises means for computing the difference between said computed location and said known location, and means for introducing respective delays in transmissions from said first, second and third antennas to calibrate said system.

46. A wireless communication system in accordance with claim 44, wherein said calibration means further comprises means for computing error indications representing the difference between said computed location and said known location, and means for storing said computed error indications for use in said means for determining the location of said receiver to calibrate said system.

47. In a wireless communication system, wherein a data packet is communicated from a base station to a subscriber station using a CDMA PN sequence, said system including at least one transfer station between said base station and said subscriber station for receiving said data packet from said base station and retransmitting said data packet using said PN sequence to said subscriber station on a first antenna to form a first transmitted data packet and retransmitting said data packet using said PN sequence on a second antenna to form a second transmitted data packet after said first transmitted data packet, a method in a receiver in said subscriber station for receiving said data packet, said method comprising:

receiving said first transmitted data packet at said subscriber station receiver forming said first received data packet;

receiving said second transmitted data packet at said subscriber station receiver forming respective second received data packet after receiving said first transmitted data packet;

wherein said system further includes retransmitting said data packet using said PN sequence on a third antenna to form a third transmitted data packet after said second transmitted data packet, said method for receiving said data packet in said subscriber station receiver further comprising:

receiving said third transmitted data packet at said subscriber station receiver forming said third received data packet after receiving said second transmitted data packet;

selecting at least one of said first, second and third received data packets to form said received data packet at said receiver;

measuring the respective time of arrival using said PN sequence phase relative to said first, second and third transmitted data packets at said subscriber station;

computing a location file comprising data corresponding to said respective measured time of arrival of said first, second and third transmitted data packets; and

transmitting the contents of said location file containing data corresponding to said measured respective time of arrival of said first, second and third transmitted data packets at said subscriber station from said subscriber station to a location service center separate from said base station.

48. A method in accordance with claim 47, wherein said location service center receives the contents of said location file containing data corresponding to said measured respective time of arrival of said first, second and third transmitted data packets at said subscriber station, computes the location of said subscriber station, and transmits the computed location of said subscriber station to said subscriber station, said subscriber station method further comprising the step of receiving and displaying said computed subscriber station location.

49. A method in accordance with claim 47, wherein said location file data is accessed by a location service center center separate from said base station, and connected to said base staion through the public switched telephone network.

50. A method in accordance with claim 47, wherein said location file data is accessed by a password and transmitted to a location service center separate from said base station through the public switched telephone network.

51. A method in accordance with claim 47, wherein said location file data is transmitted to said base station responsive to an initiation indication at said subscriber station and to a location service center separate from said base station through the public switched telephone network.

52. In a wireless communication system, wherein a data packet is communicated from a base station to a subscriber station using a cdma PN sequence, said system including at least one transfer station between said base station and said subscriber station for receiving said data packet from said base station and retransmitting said data packet using said PN sequence to said subscriber station on a first antenna to form a first transmitted data packet and retransmitting said data packet using said PN sequence on a second antenna to form a second transmitted data packet after said first transmitted data packet, an apparatus in a receiver in said subscriber station for receiving said data packet, said apparatus comprising:

means for receiving said first transmitted data packet at said subscriber station receiver forming said first received data packet;

means for receiving said second transmitted data packet at said subscriber station receiver forming respective second received data packet after receiving said first transmitted data packet;

wherein said system further includes retransmitting said data packet using said PN sequence on a third antenna to form a third transmitted data packet after said second transmitted data packet, said apparatus for receiving said data packet in said subscriber station receiver further comprising:

means for receiving said third transmitted data packet at said subscriber station receiver forming said third received data packet after receiving said second transmitted data packet;

means for selecting at least one of said first, second and third received data packets to form said received data packet at said receiver;

means for measuring the respective time of arrival using said PN sequence phase relative to said first, second and third transmitted data packets at said subscriber station;

means for computing a location file comprising data corresponding to said respective measured time of arrival of said first, second and third transmitted data packets; and

means for transmitting the contents of said location file containing data corresponding to said measured respective time of arrival of said first, second and third transmitted data packets at said subscriber station from said subscriber station to a location service center separate from said base station.

53. An apparatus in accordance with claim 52, wherein said location service center receives the contents of said location file containing data corresponding to said measured respective time of arrival of said first, second and third transmitted data packets at said subscriber station, computes the location of said subscriber station, and transmits the computed location of said subscriber station to said subscriber station, said subscriber station apparatus further comprising the means for receiving and displaying said computed subscriber station location.

54. An apparatus in accordance with claim 52, wherein said location file data is accessed by a location service center center separate from said base station, and connected to said base station through the public switched telephone network.

55. An apparatus in accordance with claim 52, wherein said location file data is accessed by a password and transmitted to a location service center separate from said base station through the public switched telephone network.

56. An apparatus in accordance with claim 52, wherein said location file data is transmitted to said base station responsive to an initiation indication at said subscriber station and to a location service center separate from said base station through the public switched telephone network.

57. In a wireless CDMA communication system, wherein data packets are communicated from a plurality of transmitters to a receiver using at least one CDMA PN sequence to form a plurality of received data packets, said CDMA communication system including first, second and third antennas spaced apart from each other, a method for determining the actual geographic location of said receiver, said method comprising:

receiving said first, second and third transmitted data packets at said receiver forming respective first, second and third received data packets;

measuring the respective time of arrival using said PN sequence phase relative to at least one of said first, second and third transmitted data packets at said receiver;

storing the geographic coordinates of said first, second and third antennas; and

computing the actual geographic location of said receiver from said stored geographic coordinates of said first, second and third antennas and said respective measured time of arrival of said first, second and third transmitted data packets.

58. A wireless communication system in accordance with claim 57, wherein said step of computing the actual geographic location of said receiver from said respective measured time of arrival of said first, second and third transmitted data packets comprises computing the difference in distance between said receiver to said first and second antennas.

59. A wireless communication system in accordance with claim 58, wherein said step of computing the actual geo-

graphic location of said receiver from said respective measured time of arrival of said first, second and third transmitted data packets comprises computing the difference in distance between said receiver to said second and third antennas.

60. A wireless communication system in accordance with claim 59, wherein said step of computing the actual geographic location of said receiver from said respective measured time of arrival of said first, second and third transmitted data packets comprises computing the position of said receiver as the intersection of first and second hyperbolas; said first hyperbola being the locus of all points having a fixed difference in distance between said receiver to said first and second antennas, said second hyperbola being the locus of all points having a fixed difference in distance between said receiver to said first and third antennas.

61. A wireless communication system in accordance with claim 57, wherein said step of computing the actual geographic location of said receiver from said respective measured time of arrival of said first, second and third transmitted data packets comprises computing a first distance to said first antenna, computing a second distance to said second antenna and computing a third distance to said third antenna, and calculating the position of said receiver as the intersection of three constant distance curves from said respective first, second and third antennas at said respective first, second and third distances.

62. A method in accordance with claim 57, further comprising:

computing a location file at said receiver comprising data corresponding to said measured respective time of arrival of said first, second and third transmitted data packets at said receiver, said location file representing the location of said receiver from said respective measured time of arrival of said first, second and third transmitted data packets containing data; and

transmitting the contents of said location file from said receiver to a base station.

63. A method in accordance with claim 62, at said base station comprising:

receiving the contents of said location file containing data corresponding to said measured respective time of arrival of said first, second and third transmitted data packets at said receiver;

computing the location of said receiver to form a computed receiver location; and

transmitting the computed location of said receiver to said receiver, said receiver method further comprising the step of receiving said computed receiver location.

64. A method in accordance with claim 62, wherein said location file contains data representing the distance to one of said first, second and third antennas, and the respective differences in time of arrival of received data packets between said one of said first, second and third antennas, and the remaining two other ones of said first, second and third antennas.

65. A method in accordance with claim 62, wherein said location file data is accessed by said base station by dial up through the public switched telephone network.

66. A method in accordance with claim 62, wherein said location file data is accessed by a password and transmitted to said base station in encrypted form.

67. A method in accordance with claim 62, wherein said location file data is transmitted to said base station responsive to an initiation indication at said receiver.

68. In a wireless CDMA communication system, wherein data packets are communicated from a plurality of transmitters to a receiver using at least one CDMA PN sequence to form a plurality of received data packets, said CDMA communication system including first, second and third antennas spaced apart from each other, an apparatus for determining the actual geographic location of said receiver, said apparatus comprising:

means for receiving said first, second and third transmitted data packets at said receiver forming respective first, second and third received data packets;

means for measuring the respective time of arrival using said PN sequence phase relative to at least one of said first, second and third transmitted data packets at said receiver;

means for storing the geographic coordinates of said first, second and third antennas; and

means for computing the actual geographic location of said receiver from said stored geographic coordinates of said first, second and third antennas and said respective measured time of arrival of said first, second and third transmitted data packets.

69. A wireless communication system in accordance with claim 68, wherein said means for computing the actual geographic location of said receiver from said respective measured time of arrival of said first, second and third transmitted data packets comprises computing the difference in distance between said receiver to said first and second antennas.

70. A wireless communication system in accordance with claim 69, wherein said means for computing the actual geographic location of said receiver from said respective measured time of arrival of said first, second and third transmitted data packets comprises computing the difference in distance between said receiver to said second and third antennas.

71. A wireless communication system in accordance with claim 70, wherein said means for computing the actual geographic location of said receiver from said respective measured time of arrival of said first, second and third transmitted data packets comprises computing the position of said receiver as the intersection of first and second hyperbolas; said first hyperbola being the locus of all points having a fixed difference in distance between said receiver to said first and second antennas, said second hyperbola being the locus of all points having a fixed difference in distance between said receiver to said first and third antennas.

72. A wireless communication system in accordance with claim 68, wherein said means for computing the actual geographic location of said receiver from said respective measured time of arrival of said first, second and third transmitted data packets comprises computing a first distance to said first antenna, computing a second distance to said second antenna and computing a third distance to said third antenna, and calculating the position of said receiver as the intersection of three constant distance curves from said respective first, second and third antennas at said respective first, second and third distances.

73. An apparatus in accordance with claim 68, further comprising:

means for computing a location file at said receiver comprising data corresponding to said measured respective time of arrival of said first, second and third transmitted data packets at said receiver, said location file representing the location of said receiver from said

respective measured time of arrival of said first, second and third transmitted data packets containing data; and

means for transmitting the contents of said location file from said receiver to a base station.

74. An apparatus in accordance with claim 73, at said base station comprising:

means for receiving the contents of said location file containing data corresponding to said measured respective time of arrival of said first, second and third transmitted data packets at said receiver;

means for computing the location of said receiver to form a computed receiver location; and

means for transmitting the computed location of said receiver to said receiver, said receiver apparatus further comprising the means for receiving said computed receiver location.

75. An apparatus in accordance with claim 73, wherein said location file contains data representing the distance to one of said first, second and third antennas, and the respective differences in time of arrival of received data packets between said one of said first, second and third antennas, and the remaining two other ones of said first, second and third antennas.

76. An apparatus in accordance with claim 73, wherein said location file data is accessed by said base station by dial up through the public switched telephone network.

77. An apparatus in accordance with claim 73, wherein said location file data is accessed by a password and transmitted to said base station in encrypted form.

78. An apparatus in accordance with claim 73, wherein said location file data is transmitted to said base station responsive to an initiation indication at said receiver.

79. A method in accordance with claim 62, further comprising transmitting a location file containing data representing said location of said subscriber station from said subscriber station to a location service center separate from said base station.

80. An apparatus in accordance with claim 73, further comprising means for transmitting a location file containing data representing said location of said subscriber station from said subscriber station to a location service center separate from said base station.

* * * * *

US005663990A

United States Patent [19]

Bolgiano et al.

[11] Patent Number: 5,663,990

[45] Date of Patent: Sep. 2, 1997

[54] WIRELESS TELEPHONE DISTRIBUTION SYSTEM WITH TIME AND SPACE DIVERSITY TRANSMISSION

[75] Inventors: D. Ridgely Bolgiano, Gladwyne, Pa.; Gilbert E. LaVean, Reston, Va.

[73] Assignee: Interdigital Technology Corporation, Wilmington, Del.

[21] Appl. No.: 538,863

[22] Filed: Oct. 4, 1995

Related U.S. Application Data

[62] Division of Ser. No. 301,230, Sep. 6, 1994.

[51] Int. Cl.[6] H04B 7/10

[52] U.S. Cl. 375/347; 375/200

[58] Field of Search 375/347, 200, 375/205; 455/49.1, 50.1, 51.1, 51.2, 52.1, 52.3, 101, 103; 370/18

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Primary Examiner—Stephen Chin
Assistant Examiner—Kevin Kim
Attorney, Agent, or Firm—Allan Jacobson

[57] ABSTRACT

A wireless communication system combines time and space diversity to reduce fading and simplify receiver design. In particular, a data packet which carries digital telephone traffic, is transmitted at three different times from three different antennas. The mobile subscriber receiver thus receives the same data packet at three different times from three different antennas, and uses the best data packet or combination of the data packets to reduce the effects of fading. A transfer station receives a time division multiplex multiple access (TDMA) signal from a base station carrying telephone data packet traffic to form three data packet repeats at spatially diverse antennas locations. The transfer station further modulates a code division multiple access (CDMA) system using a TDMA signal which links the mobile subscriber receiver to the transfer station. Each data packet received at the transfer station is thus retransmitted at three different times to the mobile subscriber station on a CDMA link. In one embodiment, each transfer station includes the three space diversity antennas. In a second embodiment, three transfer stations, each with one spatially diverse antenna is used. The time division and code division multiplex signals transmitted from space diversity antennas provide the ability to determine subscriber location using the same communication signals which are used for the primary telephone data communication. Specifically, the subscriber station receiver uses the absolute and relative time of arrival of the three repeated data packets to determine the respective distances of the mobile subscriber station to the three transmitting antennas. Since the transmitting antennas are at known fixed locations, receiver location is determined.

38 Claims, 19 Drawing Sheets

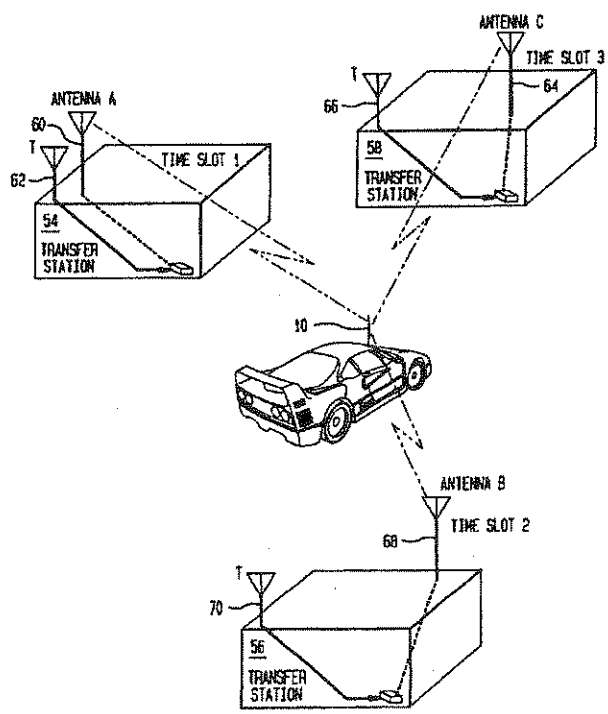


FIG. 1

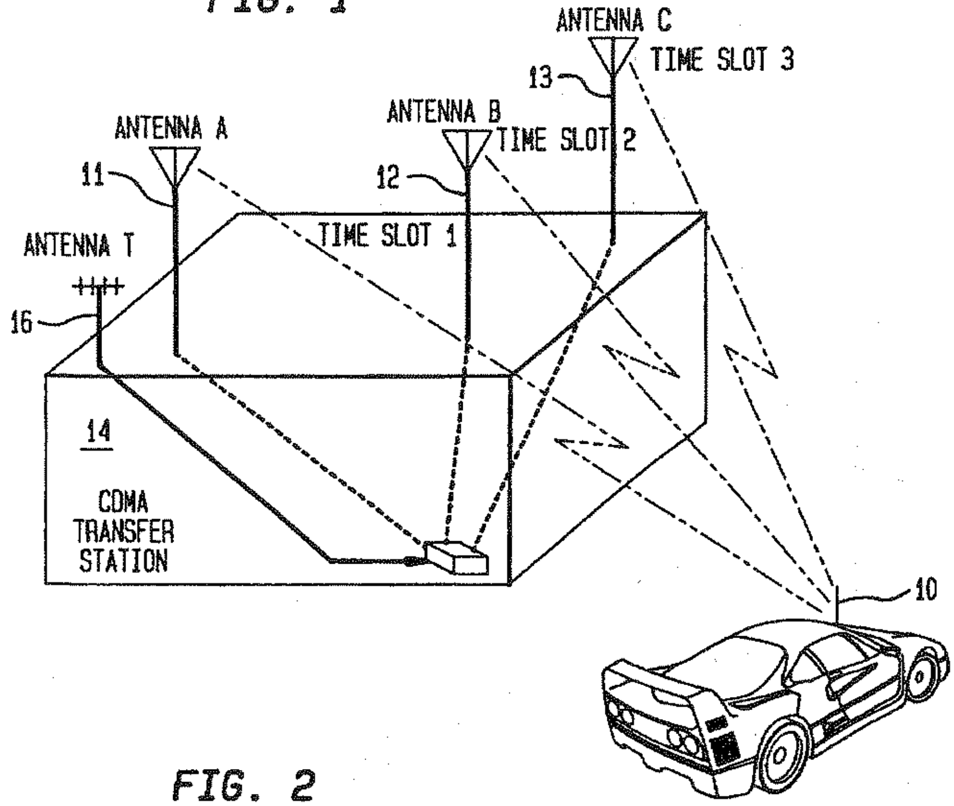

ANTENNA C
TIME SLOT 3
13
ANTENNA B
TIME SLOT 2
12
ANTENNA A
11
ANTENNA T
16
TIME SLOT 1
14
CDMA
TRANSFER
STATION
10

FIG. 2

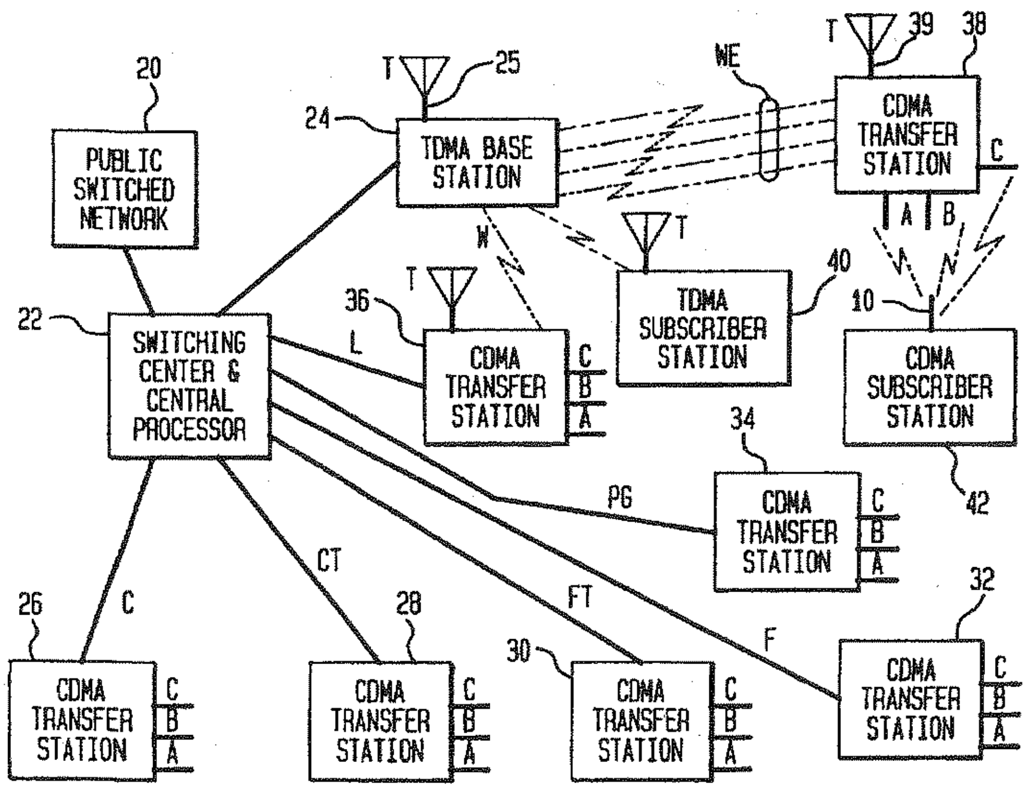

20
PUBLIC
SWITCHED
NETWORK
22
SWITCHING
CENTER &
CENTRAL
PROCESSOR
24
T
25
TDMA BASE
STATION
WE
T
39
38
CDMA
TRANSFER
STATION
C
A
B
W
T
40
TDMA
SUBSCRIBER
STATION
36
T
L
CDMA
TRANSFER
STATION
C
B
A
10
CDMA
SUBSCRIBER
STATION
42
34
PG
CDMA
TRANSFER
STATION
C
B
A
32
CT
FT
F
26
C
CDMA
TRANSFER
STATION
28
CDMA
TRANSFER
STATION
30
CDMA
TRANSFER
STATION
CDMA
TRANSFER
STATION

FIG. 3

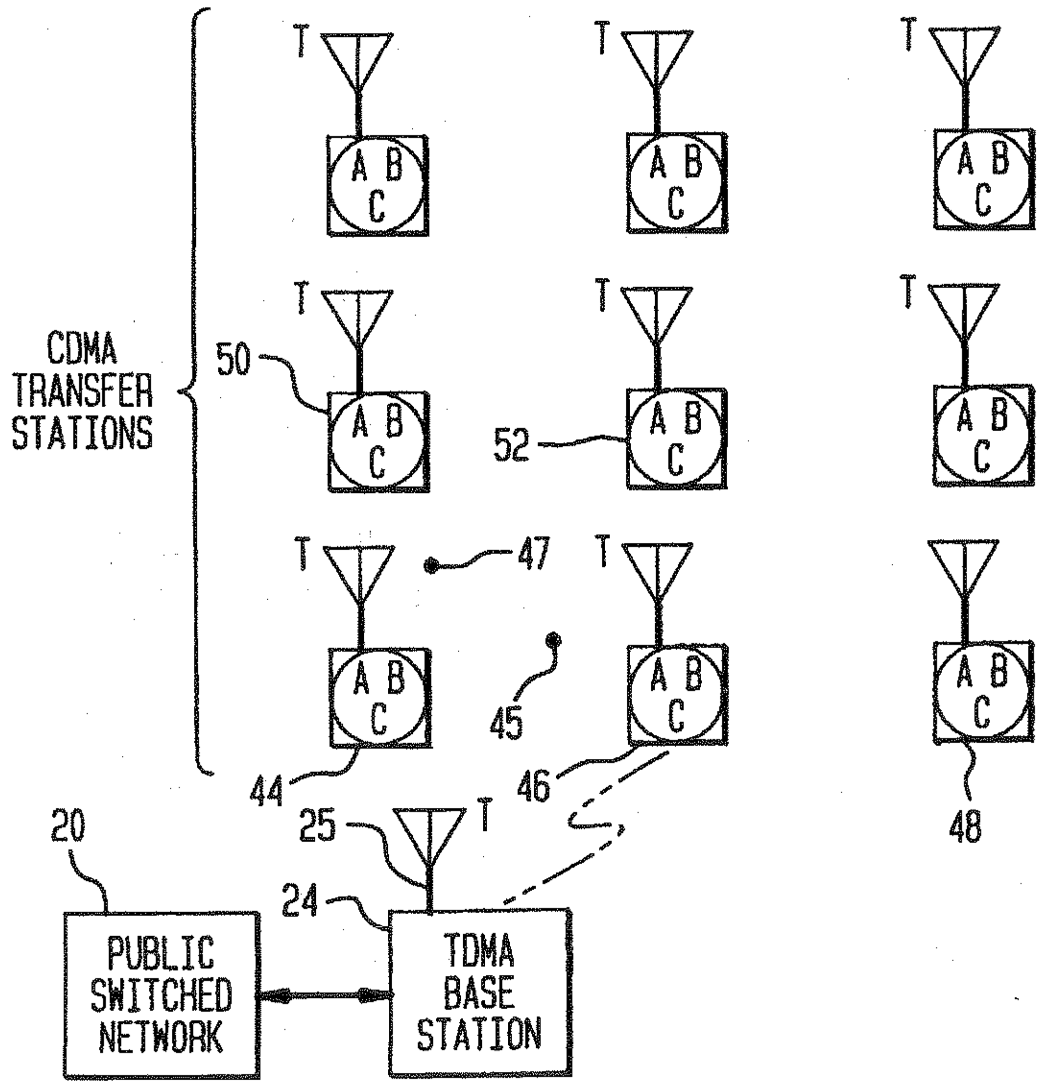
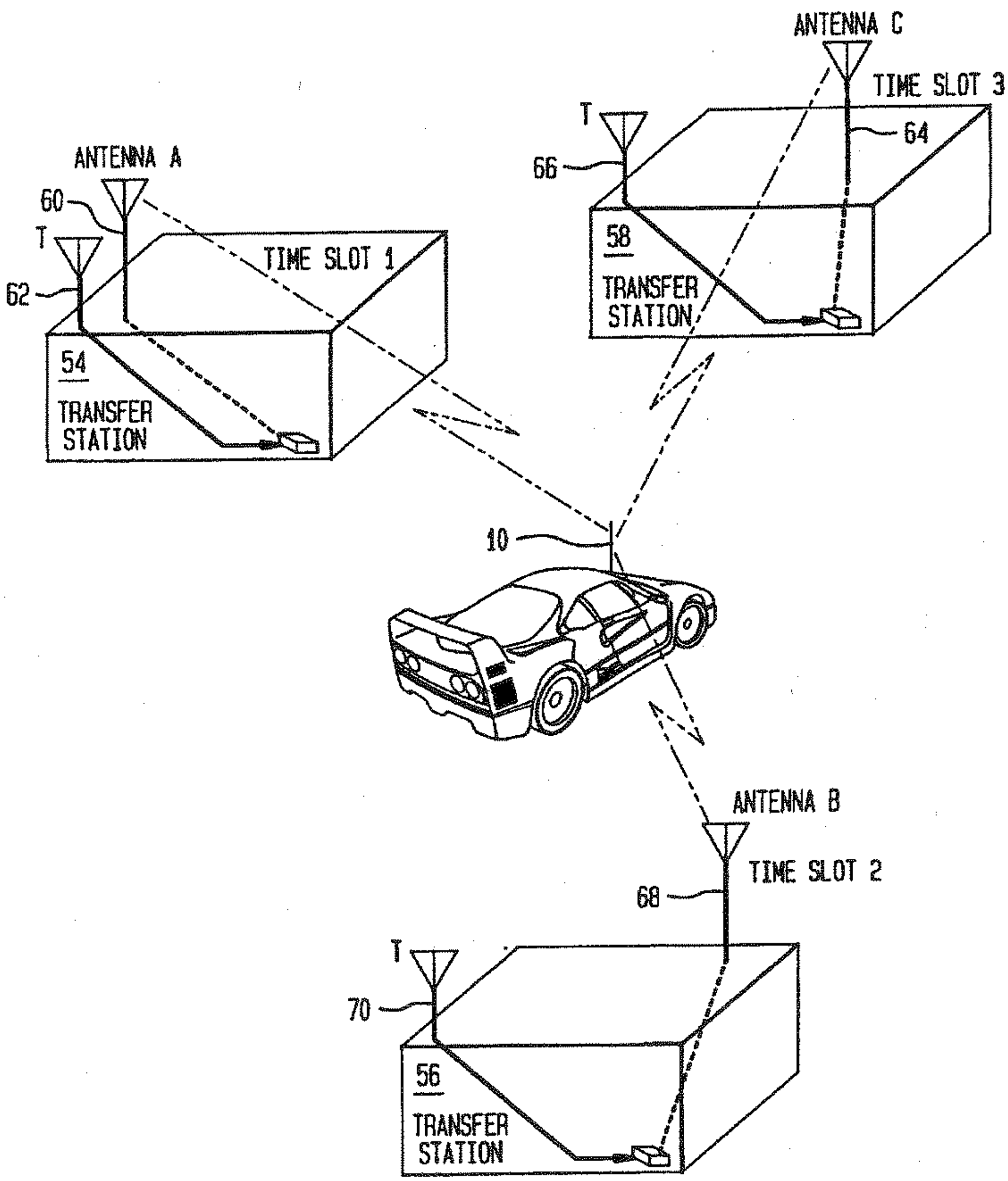
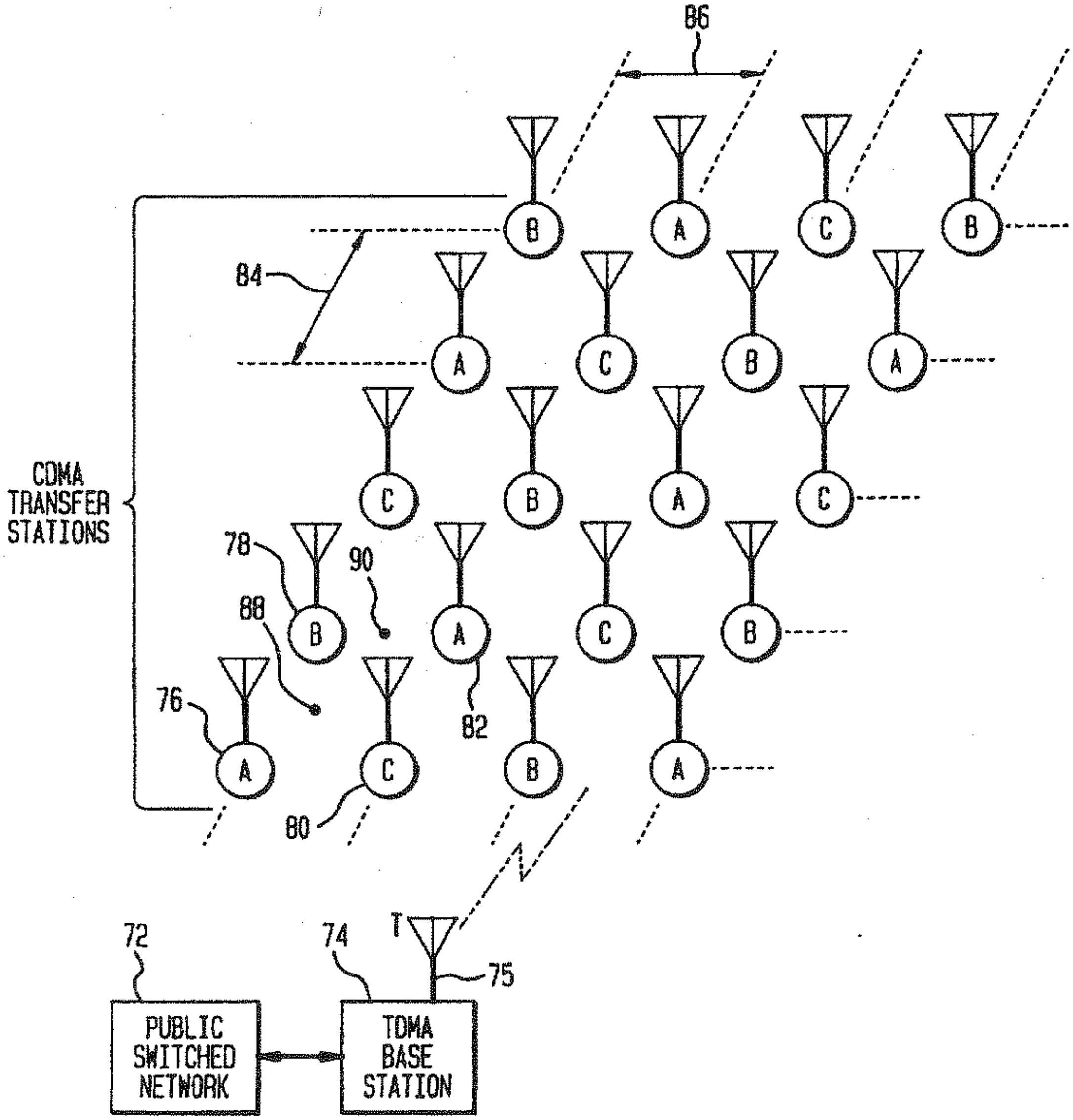

T
A B
C
CDMA
TRANSFER
STATIONS
50
52
47
45
44
46
48
20
25
24
PUBLIC
SWITCHED
NETWORK
TDMA
BASE
STATION

FIG. 4



ANTENNA C
TIME SLOT 3
T
64
66
58
TRANSFER STATION
ANTENNA A
60
T
TIME SLOT 1
62
54
TRANSFER STATION
10
ANTENNA B
TIME SLOT 2
68
T
70
56
TRANSFER STATION

FIG. 5



86
84
CDMA
TRANSFER
STATIONS
B
A
C
B
A
C
B
A
C
B
A
C
78
90
88
B
A
C
B
76
A
C
B
A
82
80
72
74
T
75
PUBLIC
SWITCHED
NETWORK
TDMA
BASE
STATION

FIG. 6

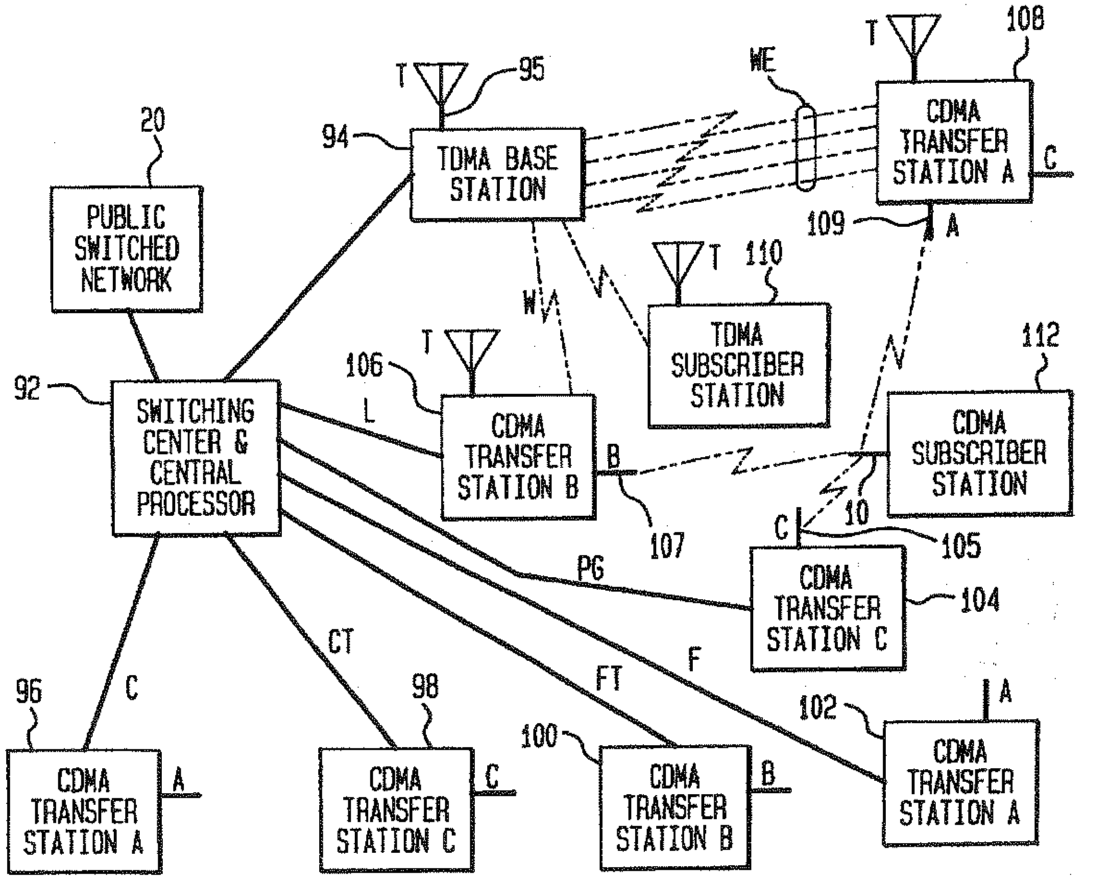


FIG. 7

TIME SLOTS	1	2	3	4	5	6
	RECEIVE	RECEIVE	TRANSMIT	RECEIVE	SCAN	SPARE

FIG. 8

TRANSFER STATION FORWARD CHANNEL

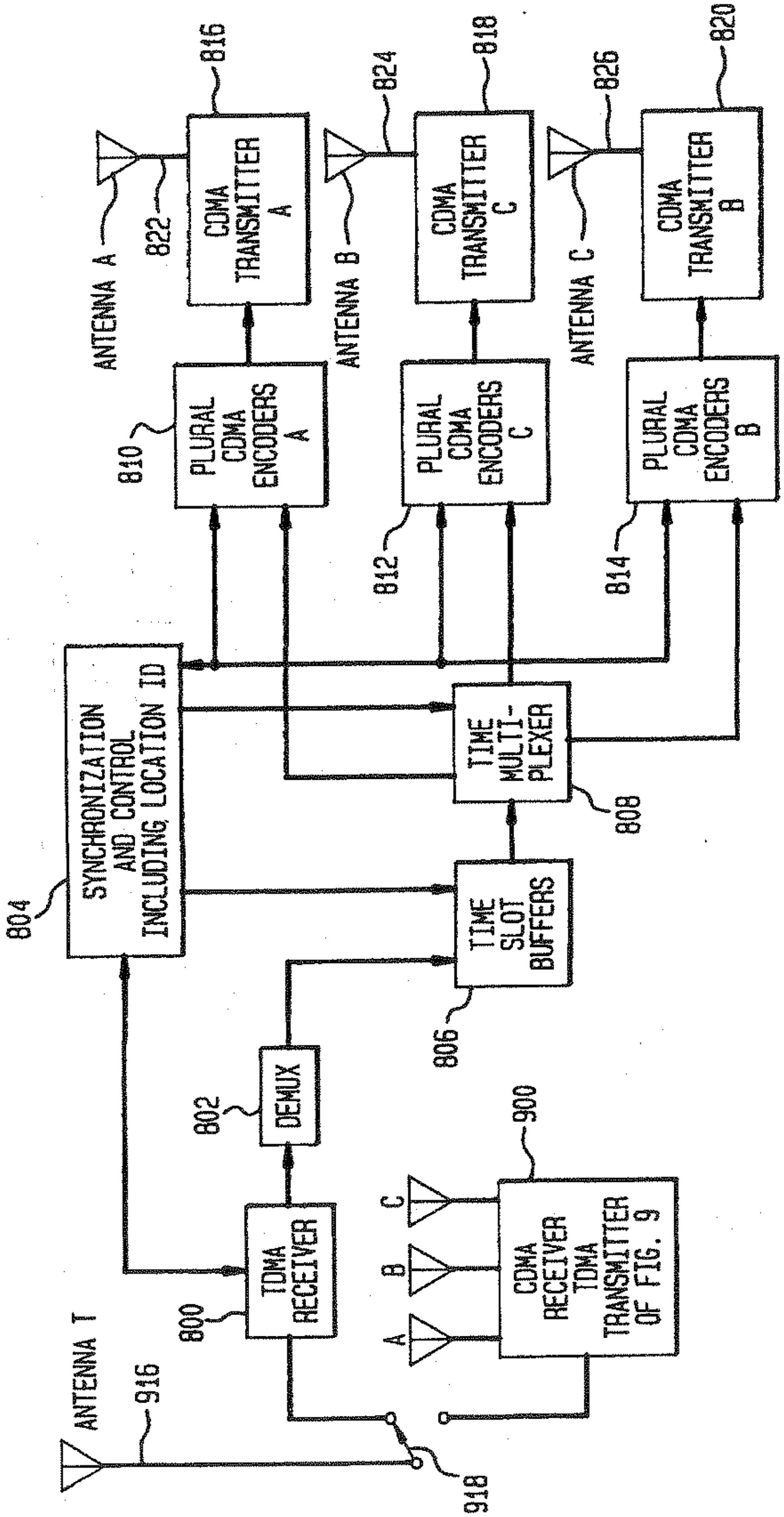


FIG. 9

TRANSFER STATION REVERSE CHANNEL

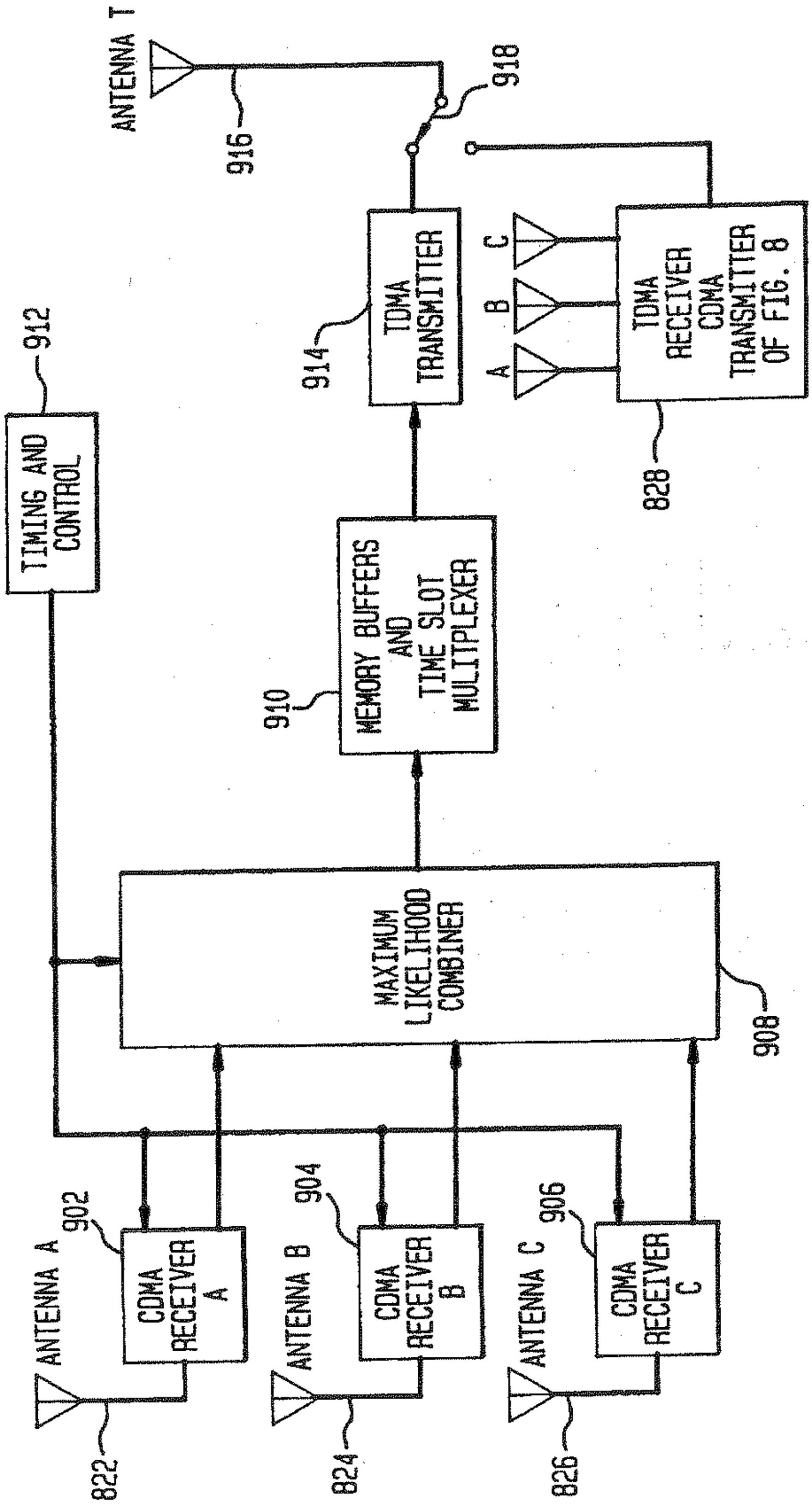


FIG. 10A

TRANSFER STATION CDMA OUTPUT TO ANTENNAS (FORWARD CHANNEL)

TIME SLOTS	1	2	3	4	5	6	1	2
ANTENNA A	T_1	T_2	T_3	T_4	T_5	T_6	T_1	T_2
ANTENNA B	T_6	T_1	T_2	T_3	T_4	T_5	T_6	T_1
ANTENNA C	T_4	T_5	T_6	T_1	T_2	T_3	T_4	T_5

1002

TRANSFER STATION CDMA INPUT FROM ANTENNAS (REVERSE CHANNEL)

TIME SLOTS	1	2	3	4	5	6	1	2
ANTENNA A	R_5	R_6	R_1	R_2	R_3	R_4	R_5	R_6
ANTENNA B	R_5	R_6	R_1	R_2	R_3	R_4	R_5	R_6
ANTENNA C	R_5	R_6	R_1	R_2	R_3	R_4	R_5	R_6

1004

T_X = TRANSMITTER CHANNEL X R_X = RECEIVER CHANNEL X

FIG. 10B

TRANSFER STATION CDMA OUTPUT TO ANTENNAS (FORWARD CHANNEL)

TIME SLOTS	1	2	3	4	5	6	1	2
ANTENNA A	$T_{1,7}$	$T_{2,8}$	$T_{3,9}$	$T_{4,10}$	$T_{5,11}$	$T_{6,12}$	$T_{1,7}$	$T_{2,8}$
ANTENNA B	$T_{6,12}$	$T_{1,7}$	$T_{2,8}$	$T_{3,9}$	$T_{4,10}$	$T_{5,11}$	$T_{6,12}$	$T_{1,7}$
ANTENNA C	$T_{4,10}$	$T_{5,11}$	$T_{6,12}$	$T_{1,7}$	$T_{2,8}$	$T_{3,9}$	$T_{4,10}$	$T_{5,11}$

1006

TRANSFER STATION CDMA INPUT FROM ANTENNAS (REVERSE CHANNEL)

TIME SLOTS	1	2	3	4	5	6	1	2
ANTENNA A	$R_{5,11}$	$R_{6,12}$	$R_{1,7}$	$R_{2,8}$	$R_{3,9}$	$R_{4,10}$	$R_{5,11}$	$R_{6,12}$
ANTENNA B	$R_{5,11}$	$R_{6,12}$	$R_{1,7}$	$R_{2,8}$	$R_{3,9}$	$R_{4,10}$	$R_{5,11}$	$R_{6,12}$
ANTENNA C	$R_{5,11}$	$R_{6,12}$	$R_{1,7}$	$R_{2,8}$	$R_{3,9}$	$R_{4,10}$	$R_{5,11}$	$R_{6,12}$

1008

T_X = TRANSMITTER CHANNEL X R_X = RECEIVER CHANNEL X

$T_{X,Y}$ = TRANSMITTER CHANNELS X AND Y $R_{X,Y}$ = RECEIVER CHANNELS X AND Y

FIG. 11A

TRANSFER STATION CDMA OUTPUT TO ANTENNAS (FORWARD CHANNEL)

ANTENNA A — 1102

TIME SLOTS	1	2	3	4	5	6	1	2
	T_1	T_2	T_3	T_4	T_5	T_6	T_1	T_2
	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}	T_7	T_8
	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{13}	T_{14}
	T_{19}	T_{20}	T_{21}	T_{22}	T_{23}	T_{24}	T_{19}	T_{20}

ANTENNA B — 1104

TIME SLOTS	1	2	3	4	5	6	1	2
	T_6	T_1	T_2	T_3	T_4	T_5	T_6	T_1
	T_{12}	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}	T_7
	T_{18}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{13}
	T_{24}	T_{19}	T_{20}	T_{21}	T_{22}	T_{23}	T_{24}	T_{19}

ANTENNA C — 1106

TIME SLOTS	1	2	3	4	5	6	1	2
	T_4	T_5	T_6	T_1	T_2	T_3	T_4	T_5
	T_{10}	T_{11}	T_{12}	T_7	T_8	T_9	T_{10}	T_{11}
	T_{16}	T_{17}	T_{18}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}
	T_{22}	T_{23}	T_{24}	T_{19}	T_{20}	T_{21}	T_{22}	T_{23}

FIG. 11B

TRANSFER STATION CDMA INPUT FROM ANTENNAS (REVERSE CHANNEL)

ANTENNA A, ANTENNA B AND ANTENNA C HAVE IDENTICAL TIME SLOTTING — 1108

1	2	3	4	5	6	1	2
R_5	R_6	R_1	R_2	R_3	R_4	R_5	R_6
R_{11}	R_{12}	R_7	R_8	R_9	R_{10}	R_{11}	R_{12}
R_{17}	R_{18}	R_{13}	R_{14}	R_{15}	R_{16}	R_{17}	R_{18}
R_{23}	R_{24}	R_{19}	R_{20}	R_{21}	R_{22}	R_{23}	R_{24}

FIG. 12
TRANSFER STATION

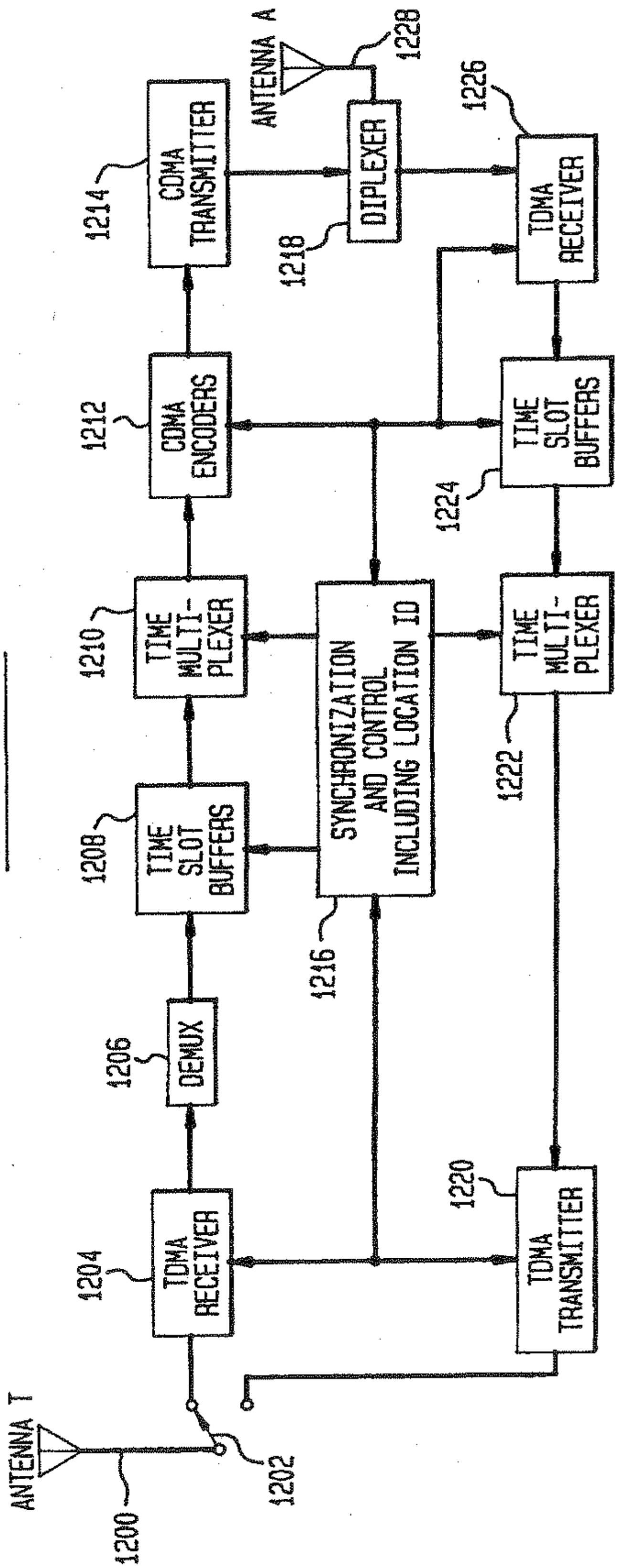


FIG. 13

SUBSCRIBER STATION

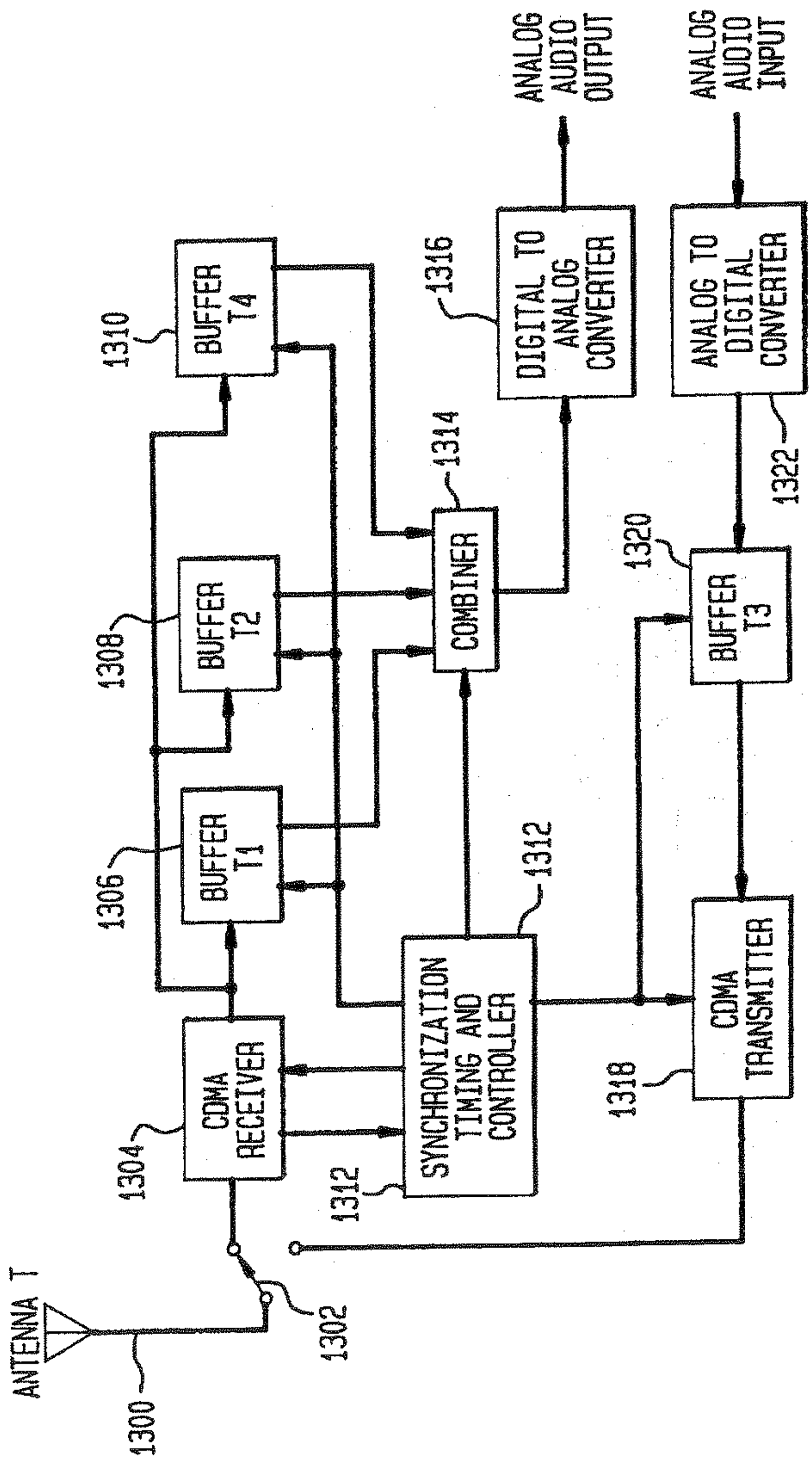


FIG. 14

CENTRALIZED AND INTEGRATED TRANSFER STATION

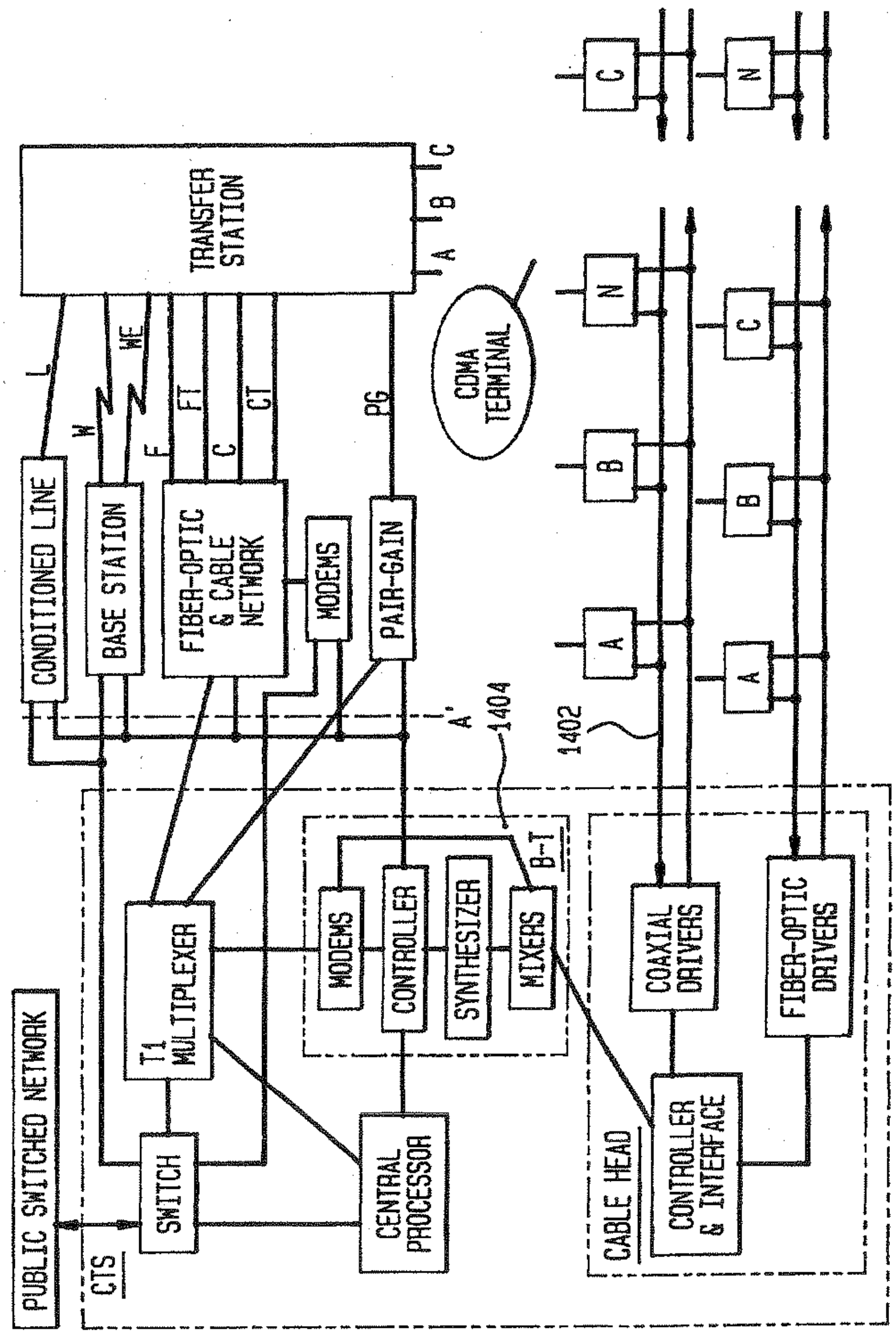


FIG. 15

TRANSFER STATION ANTENNA IMPLEMENTATION

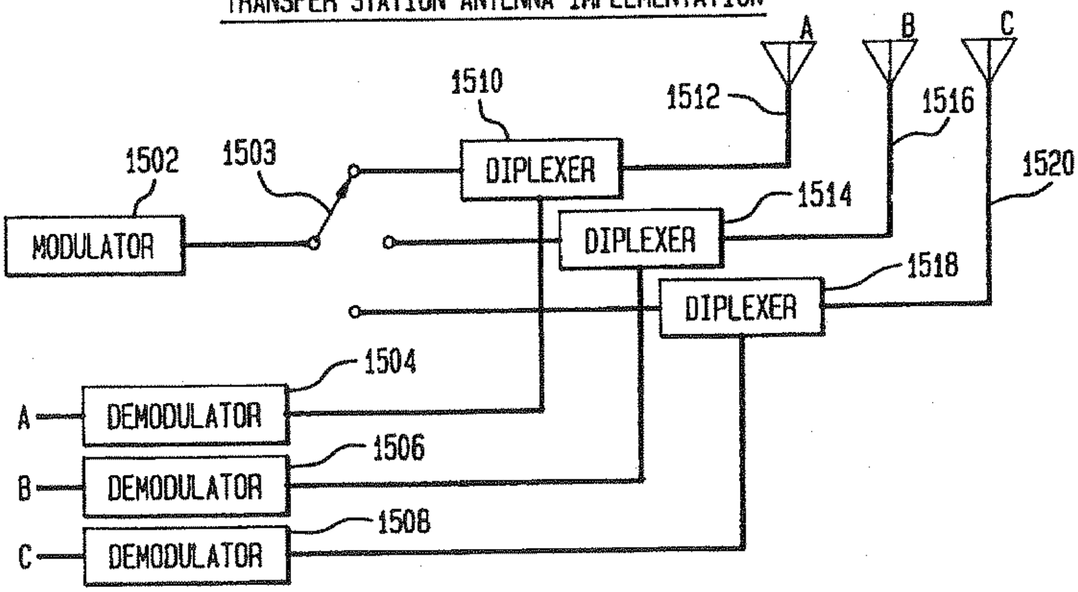


FIG. 16

DISTRIBUTED ANTENNA IMPLEMENTATION USING CABLE OR FIBER-OPTIC CABLE

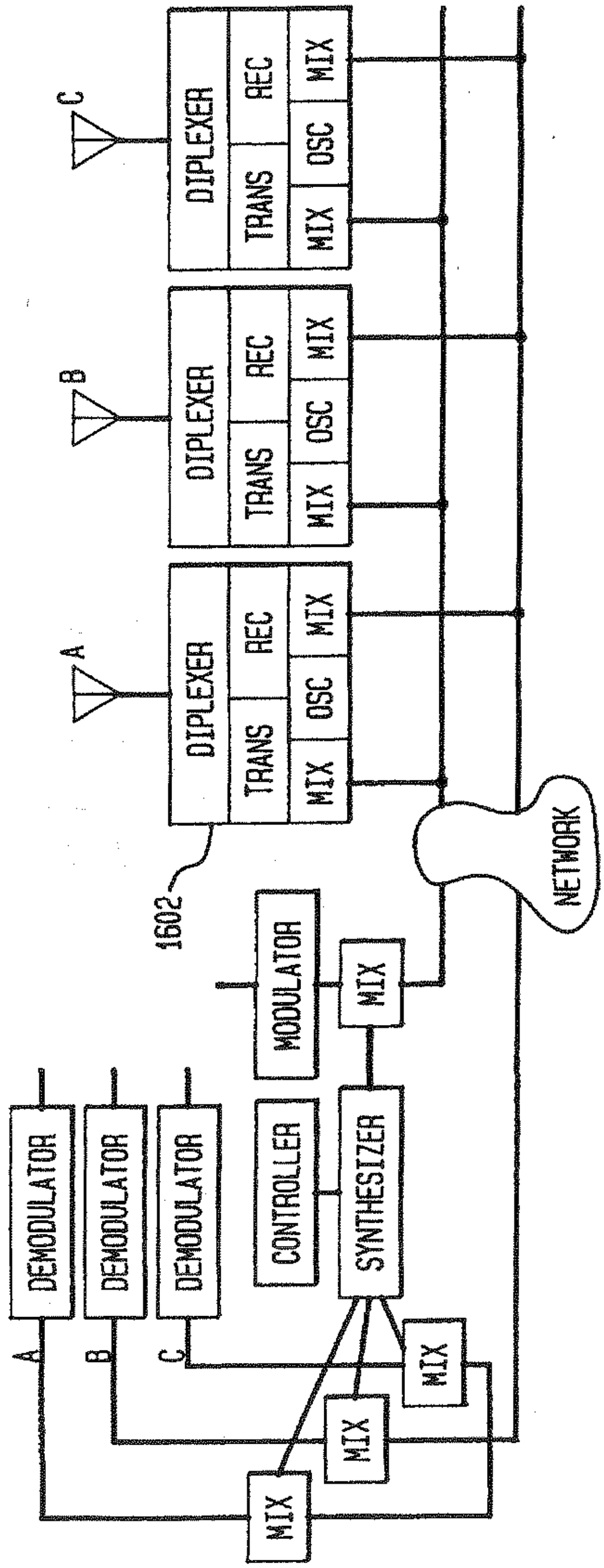


FIG. 17

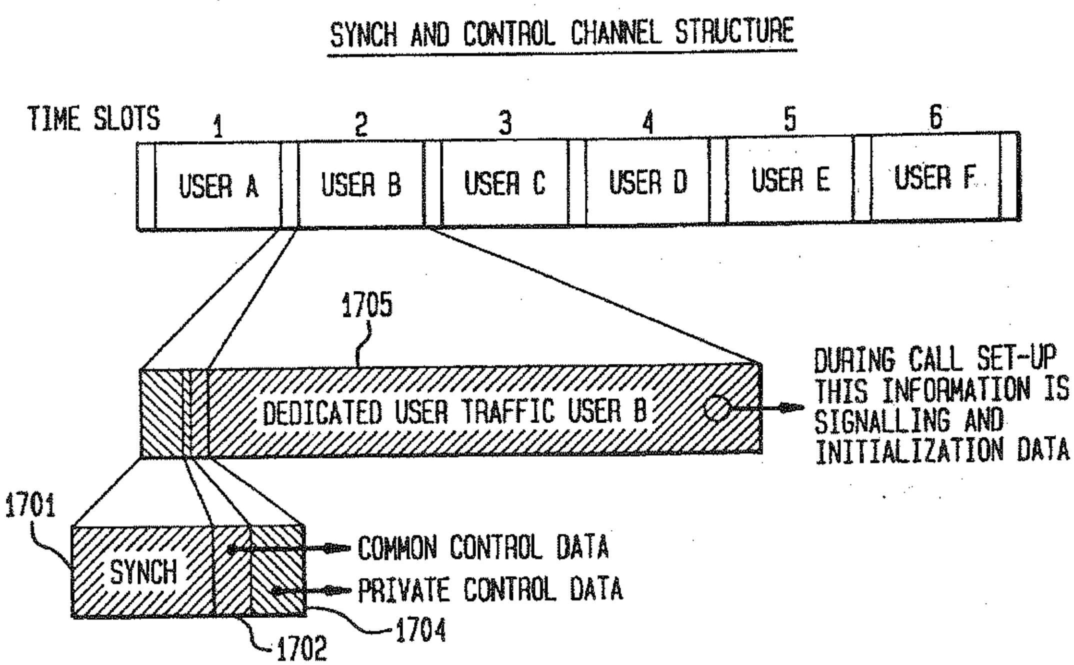

SYNCH AND CONTROL CHANNEL STRUCTURE
TIME SLOTS
1
2
3
4
5
6
USER A
USER B
USER C
USER D
USER E
USER F
1705
DEDICATED USER TRAFFIC USER B
DURING CALL SET-UP THIS INFORMATION IS SIGNALLING AND INITIALIZATION DATA
1701
SYNCH
COMMON CONTROL DATA
PRIVATE CONTROL DATA
1704
1702

FIG. 18

TIME CALIBRATION FOR DISTRIBUTED ANTENNA IMPLEMENTATION

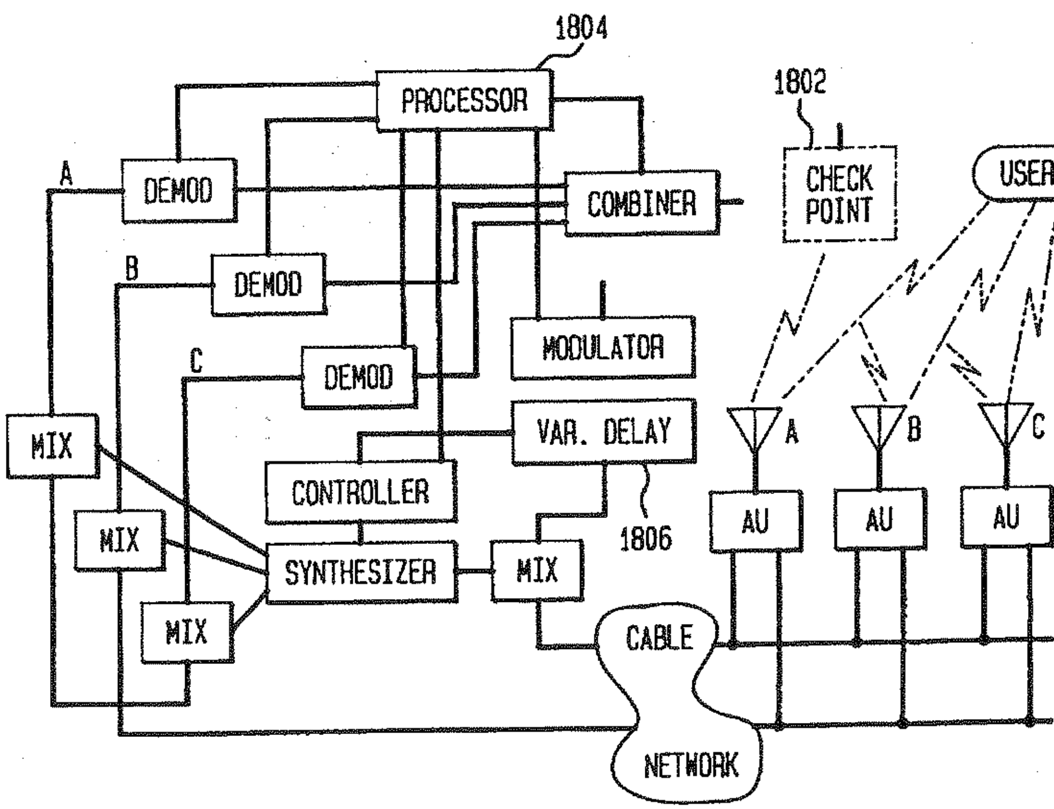


FIG. 19

LOCATION CENTER EXTERNAL TO COMMUNICAITON SYSTEM

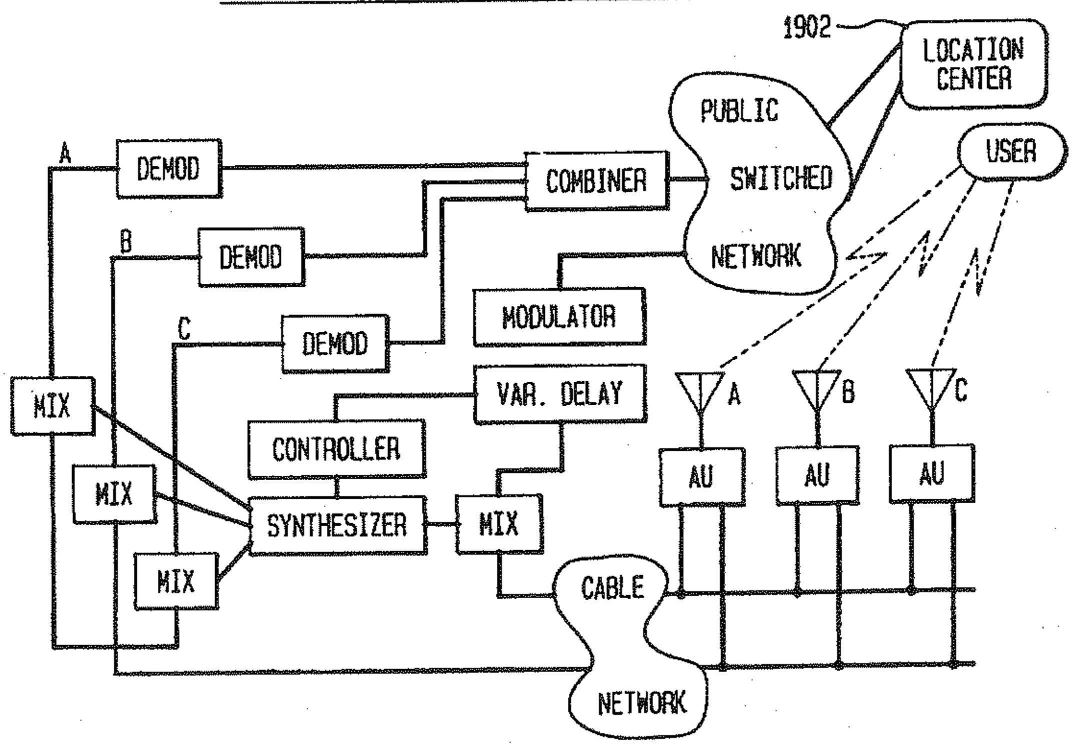


FIG. 20

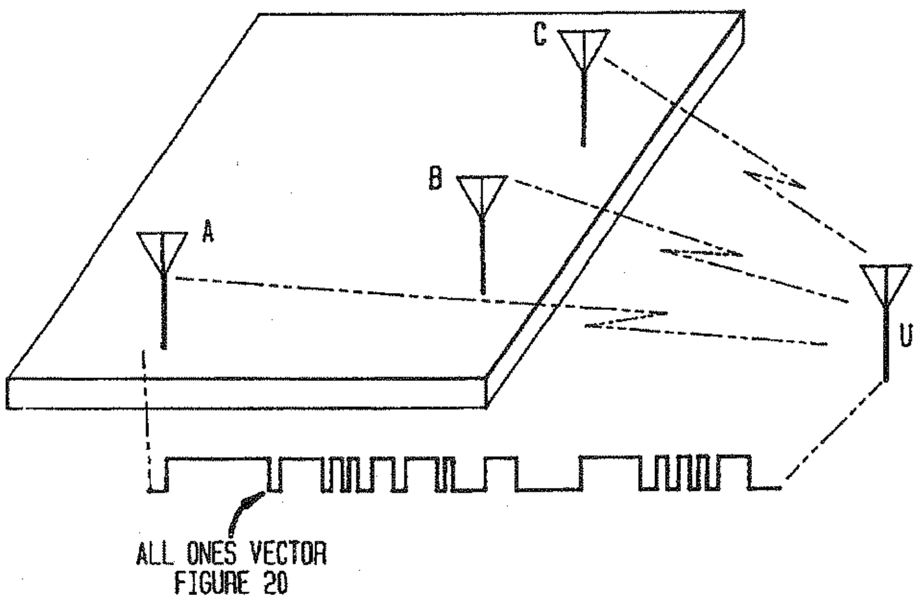

C
B
A
U
ALL ONES VECTOR
FIGURE 20

FIG. 21

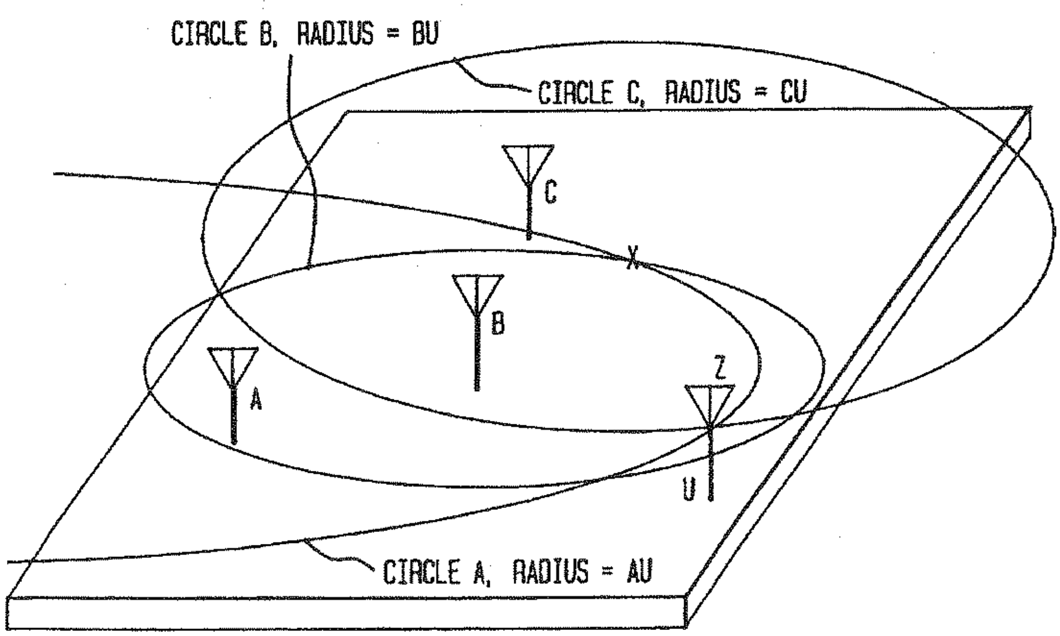

CIRCLE B, RADIUS = BU
CIRCLE C, RADIUS = CU
C
X
B
A
Z
U
CIRCLE A, RADIUS = AU

FIG. 22

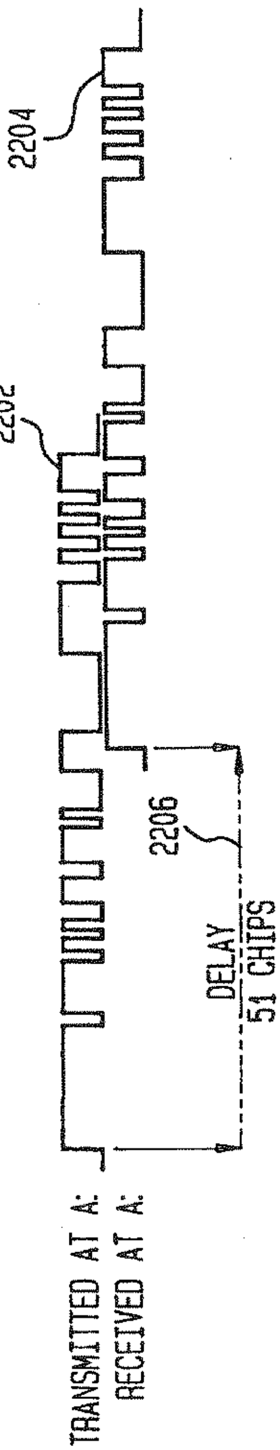
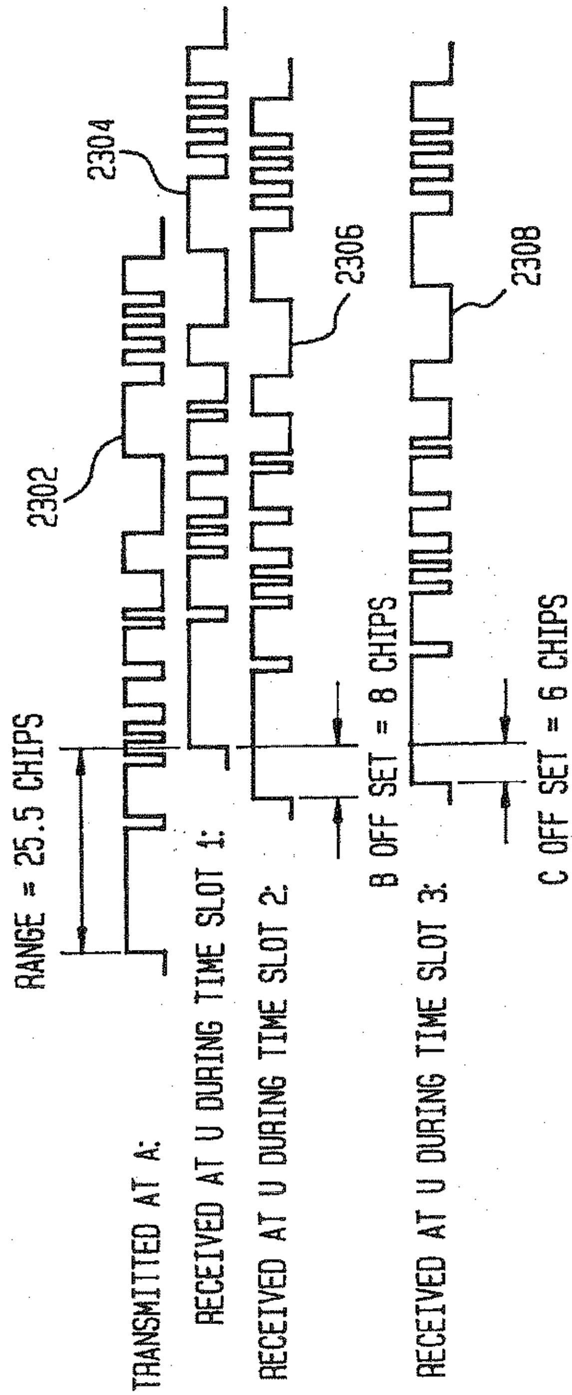

TRANSMITTED AT A:
RECEIVED AT A:
2202
2204
2206
DELAY
51 CHIPS

FIG. 23


TRANSMITTED AT A:
RECEIVED AT U DURING TIME SLOT 1:
RECEIVED AT U DURING TIME SLOT 2:
RECEIVED AT U DURING TIME SLOT 3:
RANGE = 25.5 CHIPS
2302
2304
2306
2308
B OFF SET = 8 CHIPS
C OFF SET = 6 CHIPS

WIRELESS TELEPHONE DISTRIBUTION SYSTEM WITH TIME AND SPACE DIVERSITY TRANSMISSION

This is a divisional of co-pending application Ser. No. 301,230, filed on Sep. 6, 1994.

FIELD OF THE INVENTION

The present invention relates to two way wireless communication systems. In particular, the present invention relates to wireless telephone systems with space diversity antennas and time diversity signal transmission for reducing signal fading and measuring subscriber location.

BACKGROUND OF THE INVENTION

Wireless radio communication is subject to the adverse effects of signal fading, in which the signal level at the receiver temporarily loses strength for a variety of reasons, such as from variable multipath reflections causing signal cancellation, time varying transmission loss due to atmospheric conditions, and mobile receiver movement introducing obstructions into the signal path, and the like. Signal fading causes poor reception, inconvenience, or in extreme cases, a loss of call connection.

It is known to use various forms of signal diversity to reduce fading. For example, as indicated in U.S. Pat. No. 5,280,472, signal diversity mitigates the deleterious effects of fading. There are three major types of diversity: time diversity, frequency diversity and space diversity.

Time diversity is obtained by the use of repetition, interleaving or error correction coding, which is a form of repetition. Error detection techniques in combination with automatic retransmission, provide a form of time diversity.

In frequency diversity, signal energy is spread over a wide bandwidth to combat fading. Frequency modulation (FM) is a form of frequency diversity. Another form of frequency diversity is code division multiple access (CDMA) also know as spread spectrum. Due to its inherent nature as a wideband signal, CDMA is less susceptible to fading as compared to a narrow band modulation signal. Since fading generally occurs in only a portion of the radio spectrum at any one given time, a spread spectrum signal is inherently resistant to the adverse effects of fading.

Space diversity is provided by transmitting or receiving the same signal on more than one geographically separated antennas. Space diversity provides alternate signal paths to guard against any one path being subject to fading at any one time. Space diversity also creates some time diversity since the receiver receives the same signal separated by small propagation delays. The difference in propagation delay requires that the receiver be able to discriminate between the arriving signals. One solution is to use multiple receivers, one for each arriving signal. For instance, it is known from U.S. Pat. No. 5,280,472 to deliberately introduce relatively small delays compared to an information symbol, into a space diversity multiple antenna CDMA system in order to create artificial multipath time diversity signals greater than one chip delay up to a few chips. CDMA systems are capable of discriminating between identical plural signals arriving at the receiver with different propagation delays greater than one chip delay. Such receivers are known as Rake receivers. However, prior art systems require multiple CDMA receivers, one CDMA receiver for each separate received CDMA signal. It is desirable to provide a system for receiving time diversity CDMA signals which does not require multiple CDMA receivers.

Measuring or determining the location of mobile units is well known. In some systems, fixed antennas measure the mobile location. In other systems, the mobile unit determines its location from multiple received signals. If the system is two way, the communication link permits both the mobile subscriber and the fixed system to exchange location data. Various known systems use satellites or multiple antennas to provide information on the location of a mobile subscriber. For example, multiple directional receiving antennas can be used to triangulate the position of a mobile transmitter. In such systems, the stationary receivers determine the mobile subscriber location; in other systems, the mobile subscriber determines its location from the received signals. For example, the Global Position System (GPS) is a multiple satellite system providing signals which permit a mobile subscriber station to determine its position in latitude and longitude. However, both satellite systems and the GPS receivers for receiving satellite signals tend to be expensive.

The combination of a GPS receiver and a cellular telephone is shown in U.S. Pat. No. 5,223,844. Such combination provides useful services, as for example a security alarm service to deter car theft, in which tripping the alarm also alerts the security service to the location of the car. Generally, it is desirable to provide a system which combines telephone or data service with location measurement at a reasonable cost.

It is desirable to provide a system of time diversity signals using time division multiple access (TDMA) in various combinations with CDMA and space diversity antennas, to provide a variety of systems which resist fading, reduce receiver cost, and provide location measurement for mobile subscribers.

SUMMARY OF THE INVENTION

The present invention is embodied in a wireless communication system in which time diversity and space diversity is used to reduce fading and simplify receiver design. The present invention is further embodied in a wireless communication system in which time division signals are code division (spread spectrum) multiplexed onto space diverse antennas to provide a wireless communication system with the ability to determine subscriber location using the same communication signals which are used for the primary wireless communication.

Specifically, a data packet which for example may carry telephone voice traffic, is transmitted at three different times from three different antennas. The receiver thus receives the same data packet at three different times from three different antennas. The receiver uses the best data packet or combination of the data packets to reduce the effects of fading.

In addition, the receiver uses the absolute and extrapolated relative time of arrival of the three data packets to determine its location from the three transmitting antennas. First, absolute range to one antenna is determined by the time required for a round trip message. Then, the relative time of arrival of data packets, referenced to a universal time, from the two other antennas indicates the relative distances as compared to the first antenna. Since all three transmitting antennas are at known fixed locations, the receiver computes its own location as the intersection of three constant distance curves (in the two dimensional case, circles, or in the three dimensional case, the intersection of three spheres). In the alternative, the mobile subscriber station provides raw delay measurement data back to a fixed station, or location service center, which computes the mobile subscriber location.

More particularly, the present invention is embodied in a system using CDMA to modulate a TDMA signal which is transmitted from three space diversity antennas. In a first embodiment, the TDMA signals are used to transmit multiple repetitions of the same data packet from a transfer station with three space diversity antennas. In a second embodiment, the TDMA signals are used to transmit multiple repetitions of the same data packet from three transfer stations each transfer station including one of the three space diversity antennas. The data packets could either be identical, or could carry substantially the same information, but modulated with different spreading codes or different segments of the same spreading code.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 is a system diagram of a wireless telephone distribution system including a first embodiment of a transfer station in accordance with the present invention.

FIG. 2 is a block diagram of a first embodiment of a wireless telephone distribution system in accordance with the present invention.

FIG. 3 is a system diagram of a first embodiment of a wireless telephone distribution system in accordance with the present invention.

FIG. 4 is a system diagram of a wireless telephone distribution system including a second embodiment of a transfer station in accordance with the present invention.

FIG. 5 is a system diagram of a second embodiment of a wireless telephone distribution system in accordance with the present invention.

FIG. 6 is a block diagram of a second embodiment of a wireless telephone distribution system in accordance with the present invention.

FIG. 7 is timing diagram of a time division multiplex signal which modulates a code division multiplex signal in accordance with the present invention.

FIGS. 8 and 9 are a block diagram of a first embodiment of a transfer station in accordance with the present invention.

FIG. 10A is a time slot assignment diagram of a wireless telephone distribution system in accordance with the present invention illustrating the time division multiplexing and code division multiplexing for 6 simultaneous calls.

FIG. 10B is a time slot assignment diagram of a wireless telephone distribution system in accordance with the present invention illustrating the time division multiplexing and code division multiplexing for 12 simultaneous calls.

FIGS. 11A and 11B are a time slot assignment diagram of a wireless telephone distribution system in accordance with the present invention illustrating the time division multiplexing and code division multiplexing for 24 simultaneous calls.

FIG. 12 is a block diagram of a second embodiment of a transfer station in accordance with the present invention.

FIG. 13 is a block diagram of a subscriber station in accordance with the present invention.

FIG. 14 is a block diagram of a centralized and integrated transfer station in accordance with the present invention.

FIG. 15 is a block diagram of a transfer station antenna implementation.

FIG. 16 is a block diagram of a distributed antenna implementation of the present invention using coaxial cable or fiber optic cable.

FIG. 17 is timing diagram of a time division multiplex signal which is modulates a code division multiplex signal in accordance with the present invention.

FIG. 18 is system diagram illustrating a distributed antenna implementation of the present invention.

FIG. 19 is a block diagram illustrating a system in accordance with the present wherein the location center is external to the communication system.

FIG. 20 is an illustration of a system in accordance with the present invention for determining location of a mobile subscriber station.

FIG. 21 is a system in accordance with the present invention illustrating a method for determining location of a mobile subscriber station.

FIG. 22 is a timing diagram illustrating a method for determining the distance from a subscriber station and to a transmitting transfer station.

FIG. 23 is a timing diagram illustrating a method for determining the relative distances from a subscriber station to two transmitting transfer stations.

DETAILED DESCRIPTION

System Description—First Embodiment FIGS. 1, 2, 3, 8, 9

In a first embodiment of the invention shown in FIG. 1, a mobile user having an antenna 10 is coupled to a CDMA transfer station 14. The CDMA transfer station 14 further includes an antenna T, 16, antenna A, 11, antenna B, 12, and antenna C, 13. Antennas A, B and C can be mounted either on separate structures as is shown, or on a single mast. The only physical requirement is that the space between antennas should be sufficient for uncorrelated space diversity. While a quarter wavelength spacing may be sufficient, at least ten wavelengths is preferable. At 1 GHz, 10 wavelengths is about 30 feet, while at 5 GHz, 10 wavelengths is about 6 feet.

The mobile subscriber antenna 10 (also referred herein as the user terminal antenna, or the subscriber station antenna, or simply antenna U) is coupled by a bidirectional radio link to antennas A, B and C. The CDMA transfer station 14 is further coupled by a bidirectional radio link through antenna T through appropriate switching to the public switch telephone network.

In operation, forward channel telephone voice traffic received in data packets on antenna T is transmitted on antenna A during time slot 1, repeated on antenna B during time slot 2, and further repeated on antenna C during time slot 3. All three repeated data packets are sequentially received on antenna 10. In the reverse direction, data packets representing telephone voice traffic transmitted from antenna 10 are substantially simultaneously received on antennas A, B and C. The CDMA transfer station 14 further retransmits data packets received in the reverse direction through antenna T back to the telephone network.

FIG. 2 is an overview diagram of a system in accordance with the present invention that includes the different interconnections between the supporting network, i.e., between the public switched network 20 and switching center and central processor 22, and the CDMA transfer stations 26, 28, 30, 32, 34, 36 and 38.

The user at CDMA subscriber station 42 is linked by antenna 10 to the CDMA transfer station 38 through antennas A, B and C. Antenna T, 39 on CDMA transfer station 38 carries wireless TDMA telephone voice traffic to antenna 25 on base station 24. Each of the other CDMA transfer stations are coupled to the switching center 22 by a variety of interconnection means. Connection means W between

TDMA base station 24 and CDMA transfer station 36 is a wireless means, having a TDMA channel structure with six TDMA slots. The wireless TDMA distribution interconnection WE may be a commercially available wireless local loop system such as the Ultraphone® digital radio telephone system provided by Interdigital Communications Corporation. The TDMA time slot structure is carried through the transfer station to become the time slot structure for the slotted CDMA signal on the output. Connection means WE is the same as connection W except there are four W modules operating in parallel to provide a basic connectivity for 24 voice channels. Connection means F uses a fiberoptic cable that connects between the switching center 22 to the CDMA transfer station 32 without going through a wireless base station. Since connection means F (fiberoptic cable) incorporates a modem with a TDM/TDMA channel structure similar to W and WE it readily interfaces with the transfer station. Connection FT (fiberoptic cable carrying standard T1 multiplex) between switching center 22 and CDMA transfer station 30 is a fiberoptic cable that uses a standard T1 multiplexer as the channel combining means. Therefore, the transfer station that handles the WE connection means could readily be adapted to operate with the FT connection means. Connections C (coaxial cable) to CDMA transfer station 26, and CT to CDMA transfer station 28, (coaxial cable carrying T1 standard multiplex) are cable means that function like F and FT respectively. Connection means L to CDMA transfer station 36 is a conditioned line that carries up to a 100 kb/s data stream that has the same structure as the wireless TDMA, connection means W. Connection means LE (not shown) utilizes 4 conditioned lines to function in the same way as connection means WE. Connection means PG to CDMA transfer station 34 is a pair gain capability that is interfaced into a transfer station.

Using a combination of over the air and fiberoptic/cable media, to connect to the transfer stations, and a common output air interface, between the transfer stations and the CDMA user terminals, results in a flexible rapid response and economical solution. In addition, normal telephone lines conditioned to handle 64 kb/s to 100 kb/s could also be used to replace the TDMA wireless input to the transfer station. It also is very cost effective to connect the input side of the transfer station to the output of a pair gain module. Since the air interface remains the same for all these interconnection means, this extended concept becomes a very cost effective solution and transition vehicle.

In the system diagram of FIG. 3, telephone voice traffic through the public switched network 20, is coupled to a TDMA base station 24 having antenna 25 for the transmission and reception of TDMA signals. A plurality of CDMA transfer stations 44, 46, 48, 50 and 52 provide wireless telephone service for a plurality of subscribers 45 and 47. Each CDMA transfer station includes an antenna T for receiving and transmitting TDMA signals, as well as separate antenna A, antenna B and antenna C for communicating with mobile subscribers 45 and 47. By way of example, the TDMA base station 24 may have a range of 35 mile radius covering numerous CDMA transfer stations. Each CDMA transfer station may typically have a range of five miles and be spaced three miles apart to provide cellular coverage for the entire area. Subscriber 45 will be served by CDMA transfer station 46, while subscriber 47 will be served by CDMA transfer station 50. As subscribers move about the system, a different CDMA transfer station will be assigned to serve that subscriber.

An alternate embodiment capitalizes on the rich connectivity described above to more widely distribute the three antennas that are used to give transmission space diversity. The wider distribution allows compensation for not only multipath fading, but fading due to blockage. For instance if the CDMA user (antenna 10 in FIG. 1) goes behind a building or hill the signal from all three space diversity antennas, on a single transfer station, would fade.

However, if the energy in each time slot was transmitted from different transfer stations as in FIG. 4, there is a high probability the user terminal would not be blocked from all three transfer stations at the same time. Therefore, it is possible to randomize the effects of fading due to blockage and be more similar to multipath fading. Randomization is accomplished by having the central controller assign the different time slots on an individual basis during the call setup process. When implemented using a W or WE connection means, there is little impact on the capacity between the base stations and the transfer stations, but it would increase the number of TDMA receivers. However, there is also a diversity improvement on the base station to transfer station link. Generally speaking, the impact on the other hard wired connection means is even less. A major advantage of using multiple transfer stations as transmission diversity sources is that it allows the user CDMA receiver to evaluate the quality of the signal from each transfer station and request a handoff for individual time slots as better links are found, providing a highly reliable and smooth transition as a user passes through an area.

System Description—Second Embodiment FIGS. 4, 5, 6, 12

FIG. 4 illustrates a wireless telephone distribution system with enhanced space diversity. As before, a mobile user antenna 10 is coupled to antenna A during time slot 1, antenna B during time slot 2 and antenna C during time slot 3. However, each of antennas A, B and C are mounted on separate respective CDMA transfer stations 54, 56 and 58. In particular, an antenna A, 60 is provided on CDMA transfer station 54, antenna B, 68 is provided CDMA transfer station 56, and antenna C, 64 is provided on CDMA transfer station 58. Each of the respective transfer stations 54, 56 and 58 are coupled through respective antennas 62, 70 and 66 to the TDMA wireless digital telephone system. The signals received from antennas A, B and C by the subscriber station antenna 10 are similar to that received in the configuration of FIG. 4. However, due to the separation of antennas A, B and C, at separate CDMA transfer stations 54, 58, 58, signal diversity both transmitting and receiving, is vastly improved.

The system configuration of FIG. 6 is similar to that of FIG. 2 with the exception that each CDMA transfer station has either an antenna B, or antenna B or an antenna C. For example, CDMA transfer station A, 108, has a separate antenna A, 109. The CDMA transfer station 106 has an antenna B, 107. Similarly, CDMA transfer station 104 has an antenna C, 105. Thus, the antenna 10 of CDMA subscriber station 112 receives signals from each of CDMA transfer stations 108, 106 and 104. The received signals are time division multiplexed in the sense that only one of antenna A, B or C is transmitting to antenna 10 at any one time. During transmission, however, antennas A, B and C provide multiple code division multiplexed signals to other users.

In this embodiment, each transfer station has only one type of antenna: either antenna A, antenna B or antenna C. A system arrangement covering a service area is illustrated in FIG. 5. As before, the public switch network 72 is coupled to a TDMA base station 74 having a transmitting antenna 75

covering an area of approximately a 35 mile radius. Throughout the service area, CDMA transfer stations are spaced apart in one direction 84, and in another direction 86 are positioned to cover the service area. For illustration, a regular placement is shown. In practice, the CDMA transfer stations are placed so as to provide coverage whereby a plurality of subscribers 88, 90 are always within range of an A, B and C antenna. For example, CDMA transfer stations 76 and 82 are antenna A type, while CDMA transfer station 80 is an antenna C type and CDMA transfer station 78 is an antenna B type. Thus, subscriber 88 receives signals from CDMA transfer stations 76, 78 and 80, while subscriber 90 may receive signals from CDMA transfer station 82, 78 and 80.

A time slot structure for use in the present invention is shown in FIG. 7. Six time slots are used. Time slots 1 and 2 are used to receive, followed by time slot 3 wherein the subscriber station transmits, followed by time slot 4 also used for receiving. During time slot 5 and 6 the CDMA receiver scans the transmission from other transfer stations.

Call Establishment

When a circuit is to be established or transferred, the base station assigns a base station and transfer station frequency pair, a slot and a PN sequence. It then transmits to the transfer station all of these assignments and identifies which subscriber is to use the circuit. During call setup, the transfer station passes on to the desired subscriber station, the slot and PN sequence assignments. For example, see FIG. 17 where the TDMA time slots 1 through 8 are associated with users A through F, respectively. In a given time slot, e.g., time slot 2, the message to user B contains synchronizing information 1701, common control data 1702 for system wide functions, private control data 1704 and dedicated user traffic 1705 for user B. The dedicated user traffic 1705 is used during call setup to transmit signalling information and initialization data.

Forward Path

Signal compression and decompression, plus added bits for forward error correction (FEC) is performed at the base station. In the forward direction, (to the subscriber station), the base station transmits continuously but the information in each slot is directed to a particular subscriber station.

By way of example, the base station may transmit the information during slot 1 on frequency fa. The transfer station receives the information by demodulating the signal on frequency fa during slot 1, and regenerating the information only at the symbol or bit level. The transfer station does not perform any decoding (i.e., error correction, compression or decompression) The transfer station design is thus simplified by accepting the already coded signal from the TDMA base station. After regeneration at the symbol level, the received TDMA signal is combined with the assigned PN sequence and retransmitted from the transfer station as a CDMA signal on frequency fp without any intentional delay to antenna A. The transfer station further stores the information received from the base station in a memory buffer. At the end of the antenna A transmission, the information bits stored in memory buffer are modulated onto a continuation of the PN signal and broadcast through an appropriate transmitter to antenna B. Thus, the identical information signal using the same PN sequence, but incremented a fixed number of chips, is transmitted at antenna B. The relative position, or phase of the PN sequence relative to the transmitted information is different. At the conclusion

of the first repeat, information in the time slot buffer is read out a third time to provide a third repetition of the information, modulated by a continuation of the PN sequence, with still a different phase, through an appropriate transmitter to antenna C.

Subscriber Station Processing

The subscriber station, using the correct CDMA code, receives during each of the three slots containing information signal repetition, so that it receives three identical repeats of the data packet from three antennas located in different locations. The subscriber station then compares the three receptions and selects the one with the best quality which may be based on bit error rate, phase distortion, signal to noise ratio, etc. Thus, spacial transmit diversity is achieved. Only one antenna is needed at the subscriber station. The subscriber station demodulates and decodes the signal, performs error correction, decompression, etc. A maximum likelihood combiner may be used to combine the power from all three time slots. Ideally, the energy of received data packets is combined in a maximal manner before making a hard decision.

During the third time slot T3, the subscriber station transmits back to the transfer station using a similar PN sequence as it received. The PN sequence may be the one derived from reception (after regeneration) or it can be locally generated on the basis of the original code received during call setup. Since the subscriber station does not transmit during the same time period as it receives, no diplexer or notch filter is needed. A simple T/R (transmit/receive) switch is used to switch the antenna between transmit and receive. Only one receiver is necessary in the subscriber station to achieve three branch diversity. The three chains needed by a Rake receiver, are not needed in the present invention.

Furthermore, the benefits of triple time and space redundancy, with some frequency protection provided by the expanded spectrum, are not obtained by adversely affecting capacity. The three branch diversity typically achieves a reduction for deep fades of at least 10 dB (a factor of 10×). While the three transmitted repetitions of the same information signal increases the interference level by a factor of 3 (about 5 dB), because the fades are 10 dB less, the transmitter power levels can be reduced by a factor of 10 (10 dB). Thus the overall amount of interference is reduced by a factor of 10/3 or 5 dB. Because the transfer station to subscriber link is operated in a self interference mode that means that about three times as many simultaneous subscriber circuits can be used than if diversity were not used.

Return Path

In the reverse direction (subscriber station to transfer station), three receivers are connected respectively to the three antennas at the transfer station to provide conventional three branch spacial diversity. The same analysis regarding interference and the number of circuits available, applies to transmission in the reverse direction as well as in the forward direction, except that the information is transmitted only once and is received simultaneously on the three base station antennas.

In addition to increasing the number of subscribers per unit frequency, the present invention is cost effective. First the subscriber station needs only one receiver. Second, it does not need a diplexer. Third, the transfer station does not need to decode or re-encode any signals. The number of subscribers per transmitter is the same, however, since

spacial diversity is used in the reverse direction, the number of subscribers per receiver increased. Conversely, the noise of the subscriber station can be allowed to be higher if the full use of the increase in the number of subscribers is not fully utilized.

The signal received by the transfer station from the subscriber station is retransmitted (again with symbol or bit level regeneration but without decoding), from the transfer station back to the base station without intentional delay during the same slot. As long as the slot is within the same TDMA frame or at least with one frame's duration of the slot used from the base station to the transfer station, no additional delay is incurred by the use of the present system.

Transfer Station—First Embodiment FIGS. 8, 9, 15

The CDMA transfer station has a TDMA input at antenna T. The output side of the transfer station at antennas A, B and C, uses a CDMA structure to reach a large number of subscribers in relatively densely populated areas. CDMA possesses several attributes that make it desirable for this application. The wideband signal is inherently robust in a multipath environment and it has the ability to overcome interference, intentional and otherwise. The possibility that selective fading will cause the entire spectrum to be suppressed decreases as the transmitted spectrum increases. A higher chip rate, or increased TW product, reduces the amount of fade margin that is required to achieve a specified level of performance.

Spread spectrum signals have inherent multipath protection to protect against fading. However, statistical models generally do not take into account the frequency of occurrence or the duration of the fades. The specific geometry at each location, and how the geometry is changing with regard to the receiver, determines the actual fading patterns. For small cells, with low antennas, the difference in path length for strong signals is very likely to be small. The result is flat fading. That is, the spectrum across ten or fifteen megahertz will fade at the same time. Therefore, it is not possible to use the inherent multipath protection characteristics of spread spectrum signals to protect against flat fading unless at least 25 or 30 MHz of spectrum is available. In addition, there is often no multipath of consequence that would have enough delay to gain an advantage from an additional Rake receiver. Even so the use of real or artificial multipaths, requires additional receiver/correlators in the CDMA user terminal. Therefore, to maintain reliable operation using CDMA only, at least 15 dB of margin is required to be added to the link power allocation, particularly to account for the situation where a mobile user stops in one of the nulls or a fixed user shifts location geometry slightly.

The present invention utilizes the other important characteristic of spread spectrum systems, the ability to overcome interference, as the technique to combat the difficult multipath situations. The capacity of a CDMA system is limited by the amount of interference that is received by the desired receiver. As long as the TW product is great enough to bring the desired signal up out of the interference it doesn't matter what the transmitted data rate actually is. Therefore, with the present invention the transmitted information rate is increased to allow the transmitted signal to be repeated three times from three different antennas, thus obtaining transmission triple diversity which allows the transmitted power margin to be reduced by at least 10 dB for a high performance link. Therefore, even though additional interference is introduced into the links, the CDMA processing gain readily overcomes the adverse impact. That is, the gain from the triple diversity far exceeds, in a high quality system, the loss due to added interference.

A block diagram of transfer station in accordance with the first embodiment of this invention is shown in FIG. 8 for the forward channel. The TDMA antenna T, 916, is coupled through a transfer receive switch 918, to a TDMA receiver 800. The output of the TDMA receiver 800 is coupled to a demultiplexer 802, the output of which is stored in time slot buffers 806. A time multiplexer 808 accesses the contents of the time slot buffers 806 and provides data packets output to plural CDMA encoders 810 intended for antenna A transmission. The output of time multiplexer 808 also provides data packets output to plural CDMA encoders 812 intended for antenna C transmission. Similarly, the time multiplexer 808 provides data packets output to plural CDMA encoders 814 intended for antenna B transmission. Each of the plurality of CDMA encoders 810, 812 and 814 are provided to respective CDMA transmitters 816, 824 and 826. Each of CDMA transmitters is coupled to a respective antenna 822, 824 and 826 to provide respective antenna A, antenna B and antenna C transmissions.

The coordination of the timing and control of the TDMA receiver 800, as well as the time slot buffers 806, the time multiplexer 808 and each of the plurality of CDMA encoders, is controlled by a synchronization and control apparatus 804. The synchronization and control apparatus 804 also provides a location identification (ID) representing the particular transfer station to the plurality of CDMA encoders 810, 812 and 814 for inclusion on the transmitted signals at antennas A, B and C.

The transfer station of FIG. 8 also includes a CDMA receiver and TDMA transmitter 900, which is shown in further detail in the block diagram of FIG. 9. The TDMA transmitter is coupled to antenna 916 through transmit receive switch 918, while the CDMA receivers are coupled through respective diplexers to antenna A, antenna B and antenna C, as shown in further detail in FIG. 15.

FIG. 9 is a block diagram of a transfer station illustrating the structure of handling signals in the reverse channel. Antennas A, B and C, respectively shown as 822, 824 and 826 are coupled to respective CDMA receiver A, 902, CDMA receiver B, 904, and CDMA receiver C, 906. The output of the respective CDMA receivers A, B and C is fed to maximum likelihood combiner 908, the output of which is provided to memory buffers and time slot multiplexer 910. The memory buffers in time slot multiplexer 910 provide data packets to a TDMA transmitter 914 which is coupled through transmit receive switch 918 to antenna 916. The TDMA receiver and CDMA transmitter 828 corresponding to the block diagram of FIG. 8 is coupled to the other terminal of transmit receive switch 918.

FIG. 15 illustrates the antenna configuration of a transfer station permitting antenna A, antenna B and antenna C to be shared between TDMA and CDMA transmit and receive signals. Modulator 1502 is coupled through a time multiplexer 1503 to diplexers 1510, 1514, and 1518, respectively coupled to antenna A, 1512, antenna B, 1516 and antenna C, 1520. The other input of diplexers 1510, 1514 and 1518 is respectively coupled to the output of demodulator 1504, 1506 and 1508.

In the operation of FIG. 8, a TDMA signal received on antenna 916 is demultiplexed and placed in time slot buffers 806. A data packet intended for a given subscriber is selected by time multiplexer 808 during time slot 1 to encode a CDMA signal by one of plural encoders 810 for transmission on antenna A. The same data packet is again selected by

time multiplexer 808 to encode a CDMA signal by one of plural encoders 812 during time slot 2 for transmission on antenna B. Finally, the same data packet is subsequently selected by time multiplexer 808 to encode a CDMA signal by one of plural encoders 814 for transmission during time slot 4 on antenna C.

In the reverse direction, and in reference to FIG. 9, the CDMA transmission from the subscriber station during time slot 3 is substantially simultaneously received on antennas 822, 824 and 826. Each of the CDMA receivers 902, 904 and 906 receive the same data packet. A maximum likelihood combiner 904 combines the power from all three time slots before making a hard decision. Generally speaking, the signal which is strongest and error free will be selected. After selection, the data packet is held in a memory buffer and time slot multiplexer 910 waiting to be placed in its appropriate time slot for transmission by TDMA transmitter 914 on antenna 916.

Transfer Station—Second Embodiment FIG. 12

A transfer station in accordance with the second embodiment of the present invention is shown in FIG. 12. In essence, this transfer station is similar to the transfer station of FIGS. 8 and 9 except that only one CDMA antenna, A, B or C, is provided. In particular, in FIG. 12 antenna 1200 is coupled through a transmit receive switch 1202 to a TDMA receiver 1204. The output of the TDMA receiver 1204 is demultiplexed in 1206 and placed in time slot buffers 1208. A data packet placed in time slot buffer 1208 is time multiplexed by multiplexer 1210 to one of a plurality of CDMA encoders 1212. The encoded CDMA signal is amplified in CDMA transmitter 1214, coupled through diplexer 1218 to antenna A, 1228.

Antenna A 1228 also operates to receive CDMA signals. Towards this end, a CDMA receiver 1226 is coupled to antenna A, 1228, through diplexer 1218 to provide received data packets in combiner and time slot buffers 1224. A time multiplexer 1222 takes the data packets in time slot buffers 1224 and composes a time multiplex signal to TDMA transmitter 1220 which is coupled through transmit receive switch 1202 to antenna 1200. The operation of the transfer station is controlled by a synchronization and control apparatus 1216 which also includes unique location identification (ID) for this particular transfer station, and call setup control parameters.

In operation, the transfer station receives TDMA signals on antenna T, 1200 which are demodulated in TDMA receiver 1204, and demultiplexed in demultiplexer 1206 for placement in time slot buffers 1208. The data packets in time slot buffers 1208 are transmitted on antenna A during time slot 1. Towards this end, time multiplexer 1210, CDMA encoders 1212 and the CDMA transmitter 1214 retrieve the respective data packets from time slot buffers 1208 and encode the appropriate data packet in a CDMA encoded signal on antenna A. On the return path, CDMA receiver 1226 receives signals simultaneously on antennas A, B and C during all time slots. The received data packets are demodulated by respective PN codes, and placed in time slot combiner buffers 1224, each time slot assigned to a different user. Thereafter, data packets are time multiplexed in multiplexer 1222 for transmission by the TDMA transmitter 1220 through the transmit receive switch 1202 on antenna 1200.

The Transfer Station is the conversion point for mapping the TDM/TDMA signal into a CDMA signal. The CDMA signal, when designed properly has superior performance

against multipath interference. The input side of the transfer station is part of a structured distribution network. It is basically a tandem relay point in the network, that is, the address to the final CDMA user also includes the address of the intermediary point (the transfer station). Since, in the general case, the final CDMA user may move and access the network through another transfer point it will be necessary to provide the ability to enter the transfer station address independent from the CDMA users address. For fixed subscribers such as the TDMA subscriber station 40 in FIG. 2, this will not be an issue except for backup routing or for fade protection.

The preferred input network includes a number of base stations, transfer stations and TDMA user stations as shown in FIG. 2. Any time slot on any frequency could be assigned to any TDMA user or transfer station. To reduce the cost of the transfer station it is proposed that once a CDMA user is connected through a specific transfer station any additional CDMA users, assigned to that transfer station, also be assigned to a time slot on the same frequency as the first user. By properly managing these assignments the number of TDMA radio elements can be reduced significantly. The base station 24 or the switching center and central processor 22 will manage the radio resource and assign the frequencies, time slots and the PN codes, thus assuring efficient use of the spectrum and the radios. The frequency, time slot and PN code are all assigned during the initial call setup process.

The local transmissions on the output side of the transfer station are CDMA, but each subscriber is assigned a specific time slot of a time division signal. Therefore, the individual information rate is increased by the number of time slots. However, the total data rate for all subscribers stays the same and the total transmitted power for all signals remains the same, it is just redistributed. Since the individual time slots are turned off unless there is activity the transmitted power is reduced by approximately 3 dB for voice traffic. Because the same information is transmitted three times the average transmitted power is increased by 5 dB. Therefore, the total transmitted power from each transfer station is increased by 5 dB, transmitting three times, but also reduced by 10 dB, diversity improvement, resulting in a 5 dB overall reduction in average power. Overall, the interference introduced into other cells is reduced by 5 dB.

The base station (24 in FIG. 2) or the switching center and central processor (22 in FIG. 2) will also manage the handoff process. There will have to be at least four time slots to obtain diversity on the CDMA side and still have a time slot for the CDMA receiver to scan other transfer stations. Four time slots only provide dual diversity. With five time slots it is possible to achieve the desired level of triple diversity. Of course, by adding additional receivers in the CDMA user's terminal it will be possible to scan in parallel for better synch signals. However, adding another receiver in all the CDMA users terminals would be an expensive solution. Therefore, with three time slots there is only dual diversity and no handoff. With four time slots there is triple diversity for fixed CDMA subscribers and dual diversity for mobile CDMA subscribers. With five time slots there is triple diversity for both fixed and mobile CDMA users. With six or more time slots there is the opportunity to add flexibility to the channel structure. FIG. 7 shows the CDMA user terminal slot structure for six time slots.

The triple antenna structure at the transfer station is used on the return link by simultaneously listening to a single burst from each active subscriber, in his assigned time slot, on all three antennas, thus also achieving triple space

diversity. The overall timing structure for the forward and reverse CDMA links, at the transfer station, are shown in FIG. 10A. For illustrative purposes six time slots have been shown, but as described previously any number of time slots, three or more, can be implemented, the upper reasonable bound being in the neighborhood of 32.

The order of transmission of the three active time slots can be distributed over the total number of time slots, and even more than three time slots could be used. With triple diversity the power transmitted from the CDMA user terminals can be reduced by at least 5 dB, probably more, but 5 dB is in keeping to match the performance of the forward link. In any case, the transmitted power is controlled and kept at the minimum level to maintain a high quality link. It is also possible, at higher frequencies, to achieve some antenna independence even on a relatively small radio or area. Therefore, a similar approach of the transmission space and time diversity, that is used on the forward link, may also be applied to the reverse link. Dual diversity should yield a significant improvement for most situations.

Each transfer station continuously transmits a spread spectrum channel for synchronization and control purposes. The synchronization and control channel identifies the particular transfer station and manages the user terminals as long as they are assigned to the transfer station. A large portion of the time the synchronization and control channel does not carry any user traffic. The synchronization and control channel can be a narrow band channel that can be easily acquired and tracked. The information bearing portion of the control signal has a preassigned time slot and includes system and signaling messages to all the users assigned to the particular area covered by that transfer station. The processing gain is sufficient to allow a transfer station to include several time slotted CDMA signals to be transmitted in parallel, thus allowing the antenna array to be shared. Also, only one synchronization and control channel is required for multiple slotted CDMA modules that are integrated at a single location.

Subscriber Station FIG. 13

A block diagram of the subscriber station in accordance with the present invention is shown in FIG. 13. Antenna 1300 is coupled to CDMA receiver 1304 through transmit receive switch 1302. The output of CDMA receiver 1304 provides data packets to data buffers 1306, 1308 and 1310. A combiner 1314 selects and combines the data held in buffers 1306, 1308 and 1310 to provide an output to a digital to analog converter 1316, which also includes means for decompressing the compressed signal to provide an audio output. An analog audio input is provided to analog digital converter 1322, which also provides means for compressing the audio signal. The output of the analog to digital converter 1322 is a digital form of audio samples assembled as data packets in memory buffer 1320. A CDMA transmitter 1318 encodes the contents of memory buffer 1320 and provides a CDMA encoded signal through transmit receive switch 1302 to antenna 1300. The CDMA subscriber station is synchronized by a synchronization and timing controller 1312, which also measures signal delay for location measurement, described below.

In the forward direction, CDMA receiver 1304 receives three identical data packets placing one of the data packets during time slot T1 in buffer 1306, a second of the data packets during time slot T2 in memory buffer 1308, and a third data packet received during time slot T4 in memory buffer 1310. The combiner 1314 selects one or more of the contents of the memory buffers to be combined or selected as the best received data to be converted to an analog audio output of the output of digital to analog converter 1316. By using three time and space diversity data packets, the present system is less susceptible to fading and since the same receiver is used to demodulate all three samples, no complex signal strength balancing process is required.

In the reverse direction, the analog audio input to analog to digital converter 1322, which also includes a digital compression algorithm, provides a data packet to buffer 1320. During time slot T3 the CDMA transmitter 1318 encodes the contents of buffer 1320 for transmission as a CDMA signal on antenna 1300.

The simplification of the CDMA user terminal is a major consideration in the present system. The main simplification is the ability to time share the receiver, and particularly the correlator as it performs its different functions. The ability to transmit and receive at different times also simplifies the implementation of the small portable user terminal. The single receiver sequentially receives the three space diversity signals in the three different time slots and then moves to different codes to look for improved signals from other transfer stations. The same receiver is also used for the purpose of acquisition and tracking. Since the user terminal does not receive during the slot when it is transmitting there is no need for a diplexer and notch filter. Only a simple on/off switch is used. Since only one PN code is needed at a time, the PN code generation process is also greatly simplified. The baseband processing can be accomplished on a relatively low speed common processor.

In those time slots where the user terminal is not receiving or transmitting the receiver is free to look for the synchronization and control channels from other transfer stations. When the user terminal identifies a synchronization and control channel that is better than the one he is assigned, the user terminal sends a message to the network controller telling the controller that he has identified a potential candidate for handoff. The network controller uses this input, along with other information, to make the decision to handoff. The network controller sends the handoff message to the effected entities. The identity of the codes that are to be searched by the user terminal are provided by the network central controller through the transfer station where they are placed on the control channel.

Time Slot Structure FIGS. 10A, 10B, 11A, 11B, 17

The time slot assignment for multiplexing 6 simultaneous calls is shown in FIG. 10A. Time slots assignments for transmission 1002 and for reception 1004 are illustrated. The entry in each box contains the activity during the corresponding time slot. During time slot 1, antenna A transmits T1 to user 1, antenna B transmits T6 to user 6 and antenna C transmits T4 to user 4. At the same time, antennas A, B and C receive R5 from user 5. During the next time slot 2, antenna A transmits T2 to user 2, antenna B transmits T1 to user 1 and antenna C transmits T5 to user 5. At the same time antennas A, B and C receive R6 from user 6. Continuing across the diagram in FIG. 10A, during time slot 3, antenna A transmits T3 to user 3, antenna B transmits T2 to user 2 and antenna C transmits T6 to user 6. At the same time antennas A, B and C receive R1 from user 1.

Note that during time slot 3, none of the antennas A, B or C is transmitting to user 1. Instead, user 1 is transmitting and the transfer station is receiving on all three antennas from user 1. However, during time slot 4, the third transmission to user 1 is transmitted. That is, during time slot 4, antenna

A transmits T4 to user 4, antenna B transmits T3 to user 3 and antenna C transmits T1 to user 1. Time slots 5 and 6 are not directly used for data transfer to or from user 1. The time slot assignments shown in FIGS. 10A, 10B, 11A and 11B are consistent with FIG. 7, wherein user 1 receives during time slots 1, 2 and 4, and transmits during time slot 3. The pattern can be seen in FIG. 10A slot assignments by looking for times when T1 is transmitted. Transmission of T1 appears in time slots 1, 2 and 4, on antennas A, B and C respectively. No transmission to T1 appears during T3, but reference to receiving time slots 1004 indicates that R1 is received from user 1 during time slot 3. Since in any given time slot, there are three transmissions and one reception simultaneously, at least 4 addressable CDMA PN spreading code sequences are required.

Thus, time division multiplexing is used in the sense that successive time slots carry data directed to different users. Code division multiplexing is used in the sense that during each time multiplexed time slot, multiple PN code sequences permit simultaneous communication with multiple users. The result is a time division multiplexed, code division multiplexed signal.

The time slot assignment for multiplexing 12 simultaneous calls is shown in FIG. 10B. Time slots assignments for transmission 1006 and for reception 1008 are illustrated. During time slot 1, antenna A transmits T1 to user 1 and T7 to user 7, antenna B transmits T6 to user 6, and T12 to user 12, and antenna C transmits T4 to user 4 and T10 to user 10. At the same time, antennas A, B and C receive R5 from user 5, and R11 from user 11.

The time slot assignment for multiplexing 24 simultaneous calls is shown in FIGS. 11A and 11B. FIG. 11A shows the transmission from the transfer station (forward direction), while FIG. 11*b* shows the transmission to the transfer station (reverse direction). Time slots assignments for transmission 1102, 1104, 1106 and for reception 1108 are illustrated. By way of example, during time slot 5, antenna A transmits T5, T11, T17 and T23 (i.e., T5 to user 5, T11 to user 11, etc.) Antenna B transmits T4, T10, T16 and T22. Antenna C transmits T2, T8, T14 and T20. At the same time, (during time slot 5), antennas A, B and C receive R3, R9, R15 and R21 (i.e., R3 from user 3, R9 from user 9, R15 from user 15 and R21 from user 21).

For FIG. 10A, one CDMA encoder per antenna is required to handle 6 simultaneous calls. In FIG. 10B, two CDMA encoders per antenna are required to handle 12 simultaneous calls. Similarly, in FIG. 11A, four CDMA encoders per antenna are required. Thus, for example, if 180 PN code sequences are available, then 180/6 or 30 CDMA encoders per antenna are required to handle 180 simultaneous calls. If, for these larger number of required accesses, the number of time slots is increased, the number of encoders will decrease proportionally.

Alternate System Configurations FIGS. 14, 16

A further enhancement extends the distance between the transfer station diversity antennas by using broadband cables that are a thousand feet or more. The transfer station sends the final radio frequency spread spectrum signal down the cable to the antenna. The antenna at the end of the cable contains a radio frequency amplifier. An implementation distributing signals by cable has the same improvement against blockage as described for the multiple transfer station transmission diversity approach.

However, instead of using a separate cable for each antenna, a preferred embodiment shares a single cable and

uses frequency multiplexing to assign a different cable carrier frequency to each antenna. Thus, the desired signal is only transmitted from the antenna nearest to the user which reduces the interference. As a further enhancement, a cable distribution system integrates different elements into a local personal communications system network. The basic building block is the six time slotted CDMA module that serially drives three antennas to obtain triple transmission space and time diversity. For the sake of simplicity, the design of the transfer station handling the incoming TDMA signal also has a basic six time slot structure. The six time slot modularity can readily be deployed to accommodate multiples of 12, 18, 24, and 30 or 32. FIG. 14 shows the implementation for several different combinations. The preferred embodiment utilizes a wireless input, such as W or WE, as the input to the transfer station, however, a cable distribution system works equally well with hard wired signals as the input.

In a cable based personal communication system, the transfer stations are moved back to the central controller, which reduces the cost of the transfer station since it does not have to be ruggedized or remotely powered. It also reduces the number of spares required and the cost to maintain the units since they are all in one place and easy access. The transfer stations can also be dynamically reassigned as the traffic load changes during the day or week, thus significantly reducing the total number of required transfer stations. The bandwidth of the distribution network increases, but developments in cable and fiber optic distribution system have increasing bandwidth at falling cost to accommodate the increase in bandwidth at reasonable cost. The advantage of having several interconnection options to select means that the choice of interconnection becomes an economic choice determined by the cost factors associated with each installation. Each network is expected to include many or all of the interconnection options.

The system arrangement in which the transfer stations are moved back to the same location as the central controller, is depicted in the lower portion of FIG. 14. A general two-way cable or fiber optic wideband distribution system 1402 is used to link the centrally located transfer stations to the remotely located antennas. Considerable flexibility in configuring the wideband spectrum into signal formats is available for linking the centrally located transfer stations to each transfer station antenna. However, for simplicity it is preferable to retain the TDMA protocol with its time slotted CDMA triple space/time diversity air interface protocol, and frequency translate signal as a common air interface to each antenna.

Each antenna is assigned a separate center frequency on the wideband distribution cable 1402. Due to the TDMA and CDMA sharing ability, many users can be served on the same antenna using the same cable frequency. The transfer station antenna at location N, includes a transceiver which is tuned to the assigned cable frequency. The central controller transmits and receives data packets in the final TDMA/CDMA waveform representing telephone traffic on each assigned frequency of the wideband distribution cable 1402. Thus, as shown in FIG. 16, each remote location includes a remote transceiver (transmitter, receiver, local oscillator, diplexer and antenna) at site 1602. The remotely located unit is a relatively simple receiver, frequency translator and low power transmitter, for both the forward and reverse directions. A low power transmitter amplifier is suitable because the cells are small and triple diversity (three antennas and three time slots) is being used to link the subscriber station to the system. The transmit side of the central controller provides individual information flows along with the asso-

ciated signaling and control information at interface A' in FIG. 14, which is presented in assignable time slots in the form of packets.

The signaling information includes the called parties identification number(s), code, service profile and authentication code, etc. The control information includes routing information (i.e. which base station, transfer station, antenna designation), power levels, traffic on or off, handoff messages, etc. A large amount of this information is transmitted before the user information (telephone voice traffic) starts passing over the circuit, however, a significant amount of information is also passed during the time when telephone voice traffic is actually on the circuit. A separate control channel is required even after the connection to the user has been completed. The base station function translates this information into the protocol that is required to interface to the TDMA air interface and provides a TDMA radio spectrum at interface W. The transfer station converts the TDMA protocol to a time slotted CDMA triple space/time diversity air interface protocol and transmits this signal first on antenna A, then on antenna B and finally on antenna C (FIG. 14).

The centrally located combined base station and transfer station (B-T) module 1404 combines the base station and transfer station function and converts the signal appearing on A' to the time slotted CDMA triple diversity air interface. A B-T combined module may be achieved by direct combination of separate equipment, or the modules developed for the combined base station and transfer station use can be integrated. The CDMA signal branches at the output of the transfer station or at the output of the B-T module as shown in FIGS. 15 and 16. In the case of the of the transfer stations which are connected to respective antennas by three different cables, the output is just switched at the appropriate time. When one cable is used to reach all the antennas the output of the transfer station is frequency hopped at the appropriate time by changing the synthesizer frequency to the assigned frequency of the antenna. The B-T module is similarly frequency agile.

It is important to note the user information is replicated in each of the three time slots, but the PN code continues to run and is different during each time slot. Therefore, the repetition is not the same as in the case of imitation multipath or emulated multipaths. The PN generator just keeps on running without storing or resetting the sequence. Running the PN code continuously is simpler to implement as compared to starting a PN sequence anew.

In the foregoing discussion, it is assumed the time slots follow one right after the other; this is not necessary, however, as long as the receiver has a priori knowledge of the hopping sequence. In the preferred embodiment, the B-T transmits on two contiguous time slots and then listens to the response signal from the user terminal. During the user transmission time slot the user terminal tells the B-T module to not send the third diversity time slot if the first two time slots have given adequate performance and location measurement is not needed. The use of only dual diversity reduces the interference to the other users, and frees up the user receiver to perform other functions.

An alternate approach is to utilize a ⅓ forward error correcting code that is spread over all three time slots. The use of such coding provides improved performance if the error statistics during each of the time slots are nearly the same. If one time slot becomes significantly worse, and it can be identified as being bad, it may be better to ignore the bad time slot and request an antenna handoff to replace that

time slot if the poor performance continues. Since it is expected that the real diversity channel statistics will result in unequal time slot statistics, the preferred alternative is to not use a forward error correcting code over the three time slots. Even though error detecting and correcting codes are only included within each time slot, forward error correcting codes may be used over multiple time slots.

Each antenna, assuming there is data to transmit, transmits during each of the time slots. Since the data is transmitted three times there will be three CDMA signals transmitted in each time slot for each module assigned to that antenna. If there are 4 modules assigned to the antenna, 4 modules supports 24 users at any one time, there would be 12 CDMA signals emanating from the antenna in each time slot. (see FIGS. 11A, 11B). If the duty factor is approximately 50% then only six CDMA signals will actually be transmitting and if 20 to 25% of the time the third time slot is not required only 4 to 5 CDMA signals would be transmitted at a time. The same antennas are used for the receive side, or reverse link, (user to transfer station).

As stated previously the user CDMA terminal transmits only during one time slot and the transfer station simultaneously receives that transmission on the same three antennas resulting in receiver triple space diversity. The three receive signals come into the transfer station, or B-T module, either on separate wires or at different frequencies, as shown in FIGS. 15 and 16, and are processed separately. These processed signals are summed together using maximum likelihood combiners. The S/I from each antenna path is measured and kept in memory over an interval of at least ten time slots. The record of signal statistics is used by the maximum likelihood combining process. Stored signal statistics are also useful in the decision process for executing handoff to other antennas.

The handoff process for the B-T cable network is based on the signal received from each of the antennas. The central processor receives information on the quality of the links in both directions. On the forward link it receives information from the user CDMA receiver operating on that link during an assigned time slot which is identified with a particular antenna. On the reverse link it receives information on the separate paths through different antennas. The information on the quality of paths through a particular antenna can be evaluated and compared to other current paths through different antennas and with other new paths that the user terminal is continuously searching. When a current path in a particular time slot continues to deteriorate and a better path is available the central controller assigns a new path (antenna) to the user terminal and notifies the user terminal it has done so.

The handoff process for the transfer station is similar except the handoff is generally between transfer stations rather than antennas. When handed off from transfer station to transfer station all three antennas associated with a particular transfer station are handed off with the transfer station. A few transfer stations may be implemented with widely separated antennas. In the case where there are transfer stations with widely separated antennas the handoff process described for B-T module could also be used.

Operational Description: A new subscriber turns on his CDMA user terminal and scans the synchronization codes until he acquires a synchronization code. The CDMA user terminal then initiates a registration message. The transfer station receives this message and passes it to the central controller who acknowledges it with an acknowledgment message back to the user terminal. The central controller

goes to the home register of the new terminal and obtains the user profile and places it in the file for active users. The new user is now registered and all calls will be forwarded to this new region of service.

There are 28 different synchronization codes and one synchronization code is assigned to each area. The 28 areas make up a region and the codes are repeated in the next region. The transfer stations within an area are given different shifts or starting points for their particular code. Therefore, each transfer station, or widely separated antenna, has an identifiable code. The central controller knows which antenna, or transfer station, that the new user registered through so the controller will route all information to the new user through that node. The central controller will also give the new user a set of codes, or different starting points on his current code, to search for the purpose of identifying diversity paths or handoff candidates. The new user continues to monitor the synchronization and control channel during half his time slots. The other half of his time slots he scans for better synchronization channels.

The user is paged on the control channel and given a CDMA and time slot assignment which he sets up so he will be ready for the beginning of the call. When the user requests service he is also given a CDMA code and time slot assignment for the duration of the call. The user terminal remains in this state until the end of the call, unless the signal in one or all the diversity paths becomes weak. Since the user receiver is continuously evaluating the incoming signals and scanning for better new paths, it will know if a path is going bad and will notify the central controller of this condition along with a list of better candidates. The central controller will order a handoff and the user terminal will go to the new CDMA code and time slot. None of this activity is detectable by the end user.

At the beginning of each time slot is a short unmodulated section, without user information, used for resynchronization and range adjustment, followed by a short control message section. These short bursts are sent whether there is user information to be sent or not. If no user information is to be sent the control message confirms this and the transmitter power is reduced by ten db. for the user information portion of the time slot. It should be noted four time slots are available on the forward channel for passing user information depending on what agreements have been established between the user and the central controller. These slots as described above can be turned off so that other users have access to additional capacity. The multiple time slots can be used for diversity improvement or sending increased data rates, multiple data channels or a graphics channel along with a voice channel. The possibility of extending several parties on a conference call is also possible.

Location Processing FIGS. 20, 21, 22, 23

FIG. 20 shows the radio links of FIG. 1 or FIG. 4, where the car and its antenna are represented by user antenna U. The radio links are time slotted as shown in FIG. 10A. The radio link AU is time slotted and is present during time slot 1. Radio link BU is also time slotted and is present during time slot 2. Radio link CU is also time slotted and is present during time slot 4. Radio link AU establishes the absolute range from U to antenna A. The range to antenna A forms a reference to measure the difference in path lengths between radio links AU and BU. Similarly, the path length of radio link AU is also used as a reference to measure the difference in path lengths between radio links AU and CU.

Since the time occurrence of the all ones vector (for synchronization) is the same at all three antennas, the ranges to all three antennas may be derived from the difference in respective arrival times of the all ones vector within each time slot. The location center, having the physical geographic coordinates of all three antennas, calculates the location of the users antenna U.

The geometry of location determination is shown in FIGS. 20, 21, 22 and 23. The first range measurement AU establishes the user as someplace on circle A in FIG. 21. The second range determination establishes the user as also being someplace on circle B. The only locations this can be true is where the circles intersect each other at points X and Z. Therefore, his location has been narrowed down to two possible points. The third range determination establishes the user someplace on circle C. Since the user is also on circle C, he must be at point Z. Obtaining additional ranges to other antennas confirms the first set of measurements and in many cases improves on the accuracy. If the terrain has significant variations in height the constant range circles become constant range spheres and the extra measurements remove any ambiguity that could be caused by adding the third dimension. The position location processing center converts these coordinates into user friendly instructions. Range measurements by the CDMA system are obtained as follows:

1. The pseudo noise code as it is stretched out between A and U to act as a yardstick. The time required to propagate between A and U allows many chips, the propagation time in microseconds times the chip rate in megachips, to represent the length of the link or be "stored" in the link during signal propagation. See FIG. 20.
2. There are two ways to increase the number of chips stored in the propagation path. One is to increase the path length and the other is to speed up the chip clock rate. Increasing the chip clock rate is analogous to marking a ruler in a smaller scale. Therefore, increasing the chip clock rate stores more chips in the path delay and makes it possible to make more accurate measurements.
3. The path length from antenna A to user terminal U and back to antenna A, can be measured by transmitting from A, then retransmitting the same PN code, with the arriving phase, from user terminal U, and comparing the repeated signal as it is received back at antenna A to the signal that was previously transmitted from antenna A. By delaying the original signal until it matches, chip by chip, the received signal, at A, and counting the number of chips that are slipped, the total delay is proportional to twice the distance between antenna A and antenna U.
4. The accuracy of the distance measurement is approximately ¼ of the number of feet represented by one chip. The ¼ chip is an implementation constraint determined by how precisely the correlation peak is detected and tracked. It is possible to reduce this error by autocorrelation techniques, but ¼ chip is a realistic resolution.
5. To determine the path length between antenna A and user terminal U, described in paragraph 3 above, FIG. 22 shows the signals 2202 transmitted and signals 2204 received at antenna A. At a chip clock rate of 10 megachips per second, there are approximately 100 feet represented by each chip. The delay of 51 chips between transmitted 2202 and received 2204 signals represents the time required for a radio wave to traverse a round trip between the subscriber station and the transfer station. One half of the round trip delay, or 25.5 chips represents the distance to the antenna. Thus, the distance from antenna A to user terminal antenna U for the example in FIG. 22 is (51×100)/2=2550 feet. The distance measurement accuracy is plus or minus 25 feet (100 feet/4).

6. Thus, the distance AU is measured quite precisely. As described previously the receiver uses a single receiver for all time slots. While the subscriber receiver is listening to time slot one it is working in conjunction with the base station, to repeat the received waveform, same phase with no delay through the user terminal. The base station receiver, as described above, compares the received phase with the transmitted phase to determine absolute range. The base station then transmits the range value, thus measured, to the user terminal where it is stored for future retrieval and use. As noted above it is the waveform phase that is important, if the starting point, the all ones vector, is maintained through the user terminal, a new similar PN code may be substituted on the reverse link. A similar code could include that same code shifted by a defined offset.
7. The same forward and return measurement process described above, could be used to obtain the other two ranges (to antennas B and C) with the results also stored in memory at the user station. However, direct range measurement to all three antennas is not necessary. See FIG. 23. The same receiver retrieves information over all three paths. In so doing, the receiver adjusts for the difference in path length at the beginning of each time slot. Once the adjustment is accomplished, on the first time the receiver uses this antenna as an information channel, the code is stored and retained in memory until the radio returns to this time slot whereupon, it is taken from the memory and used as the starting point for the tracking loops. Therefore, the receiver is essentially maintaining three separate sets of receiver parameters, emulating three different receivers, one set of parameters for time slot 1, a different set for time slot 2 and still a different set for time slot 3. The distances to antenna B and antenna C can be determined by adding or subtracting the offset, measured in chips, from the absolute range value measured on link AU. Actually the offset is determined before the time slot is used for the first time as an information channel, this determination is made in the process of looking for new paths for handoff. The delay and measure of signal quality is determined and maintained in the potential handoff targets file. These delay offset measurements are also used as additional range measurements in the position location process.

In particular, continuing the above example, the signal 2302 transmitted at antenna A represents a range of 25.5 chips from antenna A to user terminal antenna U. Signal 2304 received at antenna U from antenna A is used as a reference to measure the relative time of arrival of signals from antennas B and C, adjusted for the different time slots in which these signals are placed.

Since timing for time slots 1, 2 and 3 is sequential, the real time chip patterns for slots 2 and 3 do not overlap. However, after adjustment for time slot delays, the timing relationship is as shown in FIG. 23. Thus adjusted for the time slot difference, signal 2306 received from antenna B at user terminal antenna U, is received in advance (i.e., offset relative to the signal from antenna A) by 8 chips. Similarly, signal 2308 received from antenna C at user terminal U, is also received in advance (i.e., offset relative to the signal from antenna C), but by 6 chips. Received signals may be either delayed or advanced (i.e., have a positive or negative delay) relative to the reference signal 2304. Receipt in advance indicates that the antenna (B or C) is closer than antenna A. Conversely, a delayed receipt indicates that the antenna (B or C) is further away than antenna A.

In FIG. 23, the range from antenna B to antenna U is 25.5−8=17.5 chips. In feet, 17.5 chips is 17.5×100=1750 feet, the length of path BU. The range from antenna C to antenna U is 25.5−6=19.5 chips. In feet, 19.5 chips is 19.5×100=1950=path length CU. The user terminal may be located at Z, the intersection of circle A at 2250 feet from antenna A, circle B at 1750 feet from antenna B and circle C at 1950 feet from antenna C.

In the alternative, location measurement may be accomplished by computing the intersection of two hyperbolas. The first hyperbola is the locus of all points having a fixed difference in distance from two foci, which is proportional to the difference in delay between antenna A and antenna B. The second hyperbola is the locus of all points having a fixed difference in distance from two foci, which is proportional to the difference in delay between antenna B and antenna C, (or antenna A and antenna C). Antennas A and B are the foci of the first hyperbola, while antennas B and C are the foci of the second hyperbola. In such manner, subscriber location may be computed without requiring a two way exchange between the user terminal and the transfer station to establish a first range measurement.

Location Services FIGS. 18, 19

Since, the subscriber station receiver is receiving information over three different paths that emanate from known locations, position location information is derived by measuring the time of arrival of messages relative to a fixed time reference. The measurement accuracy depends on the chip rate, but at a chip rate of 10 megachips per second it is quite accurate. There are several ways location measurement and display can be accomplished, depending on how much processing is available in the user terminal. The choice also depends on who will actually use the information. It could be fairly passive, using only the relative chip offset information and obtaining a reference from the current cell. The user could locally derive and display his location, similar to using a GPS satellite. A GPS receiver displays longitude and latitude reading. Location information may also be sent back to a processing center that provides a service to the user. The processing center converts the longitude and latitude coordinates into a location having geographic meaning, such as, a block number on a specific street.

Local geographic position measurement is particularly attractive to people concerned about security and health problems. The manager of the service center could either notify the police, family designate or the service center could include, as part of a special service rate, the staff to check on irregular circumstances. Of course, the service center can also, for a nominal fee, tell an individual his street location and give instructions on how to get to a desired destination address. These services can be provided to users who are pedestrians or moving along in vehicles. The destination instructions can be in the form of a set of one time detailed directions, or specific and continuous intersection prompting as the user travels the suggested route. The prompting could take the form of a voice command, or text display, telling the user to turn right at the next intersection. A delivery truck, cab, ambulance or fire truck could have a special screen that showed a local map with instructions written on it. The instructions can also be modified as the traffic congestion changes. The benefits of the present system are a significant increase in public safety, convenience and productivity.

In the system configurations described previously, the separation between antennas is made sufficient to yield an accurate position location capability. By positioning the antennas to obtain independent paths sufficient to avoid flat fading due to interfering obstacles, then the separation is

also sufficient to reduce the triangulation error to a very small number. The incremental cost of including optimization for a location capability is nominal.

Position location processing is accomplished by a third party provider which owns and manages the position location center. Location service can be accomplished in several ways. The preferred approach is to make the user terminal the repository for all location information by building and maintaining a location file. The position location center queries the user terminal over the normal public switched telephone network (preferably packet) when it needed information. Preferably, a provision for encryption during transmission and an access code for privacy, is used. The user terminal could also send location information to the location center, also over the public switched telephone network, responsive to user activation. For instance, when the user pushed an alarm button, the radio sends the alarm message, along with the location information, to the location center. The location center would respond according to prearranged directions and the level of subscribed service. Since the user terminal radio develops the code offset information internally, the only additional information the cellular system needs to provide to the user terminal is the distance, one way or round trip, from the user to one of the base station/antennas. The distance information, which would be provided as a service feature to the user, must identify the base station/antenna. All the measurements must be performed within a time window of 100 milliseconds or the error as a result of vehicle movement between measurements could become excessive. For stopped vehicles or pedestrians the time window to perform location measurements could be much longer since there is little or no movement between measurements. Therefore, the distance measurement sent by the system to the user terminal includes the distance in feet, the time in milliseconds and the identity of the measuring entity. Upon receipt of the distance message the user terminal stores the message and makes code offset measurements to several different antennas, and, if signal levels are adequate, stores the composite information in the location file. The location file is retained until a new distance message is received by the user terminal radio, whereupon the user terminal radio again makes the code offset measurements and updates the location file.

When the location center queries the user terminal radio as to its location, the radio sends the contents of the location file. The location center processes this data into very accurate map data, position on a particular street (can be displayed on a typical street map) The system measures distance to the subscriber normally once every minute when the subscriber is in the active receive mode, receiver on, waiting to be paged. The period between measurements is variable and can be adjusted according to the needs of the user. The system sends this new distance to the subscriber station which places it in the file and enters new code offset measurements with it. If the subscriber is engaged in a conversation, the user terminal is transmitting, the base station makes a measurement every ten seconds and if the distance changes more than one hundred feet the system sends a message to the subscriber station. Whenever the user terminal receives a distance measurement it adds the local code offset measurements and updates the file.

It can be seen the user terminals location file is updated at least every minute and more often if warranted. Therefore, the system can know the location of any active user within a distance of approximately 100 feet. Better accuracy and more frequent updating is certainly possible, but due to the loading on the data links the number of subscribers receiving higher performance should be the exception rather than the rule. Whenever the user presses the alarm button on his portable terminal, the terminal transmits the contents of the location file three times which is long enough for the system to read a new distance and send a message to the user terminal. The user terminal makes several offset measurements and sends the new location file three times. The alarm message is repeated every thirty seconds until the battery goes dead. The user terminal radio can have a module added (with its own battery) that emits an audible tone whenever the radio alarm message is transmitted.

The system generates raw location information at the user terminal that needs to be converted into human readable map data. In general, the basic longitude, latitude, or angle and distance readings are fine. However, there is a need for a third party to translate this data into a format that is quickly usable by the mass public, as a service business. Since the user terminal has the basic location information, it can be provided to any authorized entity that requests it from the user terminal. The location processing center periodically queries the subscribed user terminals and maintain a file on their current location. One potential service for subscribers with health problems, is a monitoring system during exercise. If the subscriber stops in an unusual location for an excessive length of time and does not press the alarm button, the location center operator could request life signs or send a medical technician to the paused subscriber. If there is an emergency, the location center operator knows the subscriber location in order to send help. On the other hand, when the alarm button is pressed, the alarm message is addressed to the location center where they are equipped to handle such emergencies. The capability to track user terminals and provide help as the result of some action is useful for many applications. Tracking stolen cars, identifying congestion, keeping ambulances from getting lost and reporting vandalism are but a few examples of the application of the present invention.

The system does, particularly in its distributed configuration as described previously, require a consistent zero time reference across the different base station antennas. Having a zero time reference available significantly reduces the time to resynchronize as the signal hops from antenna to antenna and also aids in the search and handoff process. The location application capability described above allows the system to periodically perform a self calibration by placing several of the user terminals, as described above, at fixed locations and determining the proper zero time setting for these locations. By keeping the correct answer in the central processor, as the system scans these check points, it will get an error indication if the system is out of calibration. The same check points are used to show the effective delay, during the process wherein a variable delay is introduced by incrementing or decrementing the system delay in one or more of the signal paths in the recalibration or adjustment process.

The calibration process could be easily automated. Automation could be implemented in two ways. The first approach is to scan the check points every minute and determine any error that has developed. If this error reaches a significant level the communication system contacts the location center and provides the center with the corrections that need to be factored into the position location calculations. The latter approach requires close coordination between the communication system and the position location center. A more autonomous approach would be desirable. The communication system itself could maintain the proper "zero" state by scanning the check points, as described above, and by having the ability to insert or remove delay 1806 in the path to the antenna.

FIG. 18 illustrates a system with self-calibration. Once every minute the system queries each check point 1802. This results in a distance measure being sent to the check point 1802 where the check point receiver adds the code offset measurements and sends the contents of the location file to the processor 1804 where the received file is compared with a file that contains the correct measurements. If the difference exceeds the threshold the processor 1804 calculates the changes in delay that are required to bring the measurements within tolerance and passes the correction to the controller. The controller maintains a file that includes the variable delay 1806 to be inserted for each antenna. The controller changes the delay entry in the file and a new measurement is taken to validate the calibration. Changes that require significant changes in delay are unlikely, but if this should happen the controller would not initiate any measurements that include the leg that is under recalibration. Thus, the position location capability also provides a service for the communication system. Self calibration results in a significant reduction in installation cost and allows the use of more economical system components.

Location related communications between the antenna devices and the subscriber terminal can be broken into several different links. The functions that are performed by these different links are: 1, distance measurement (requires a two way link, but no traffic); 2, sending measurement information to subscriber terminal (one way data link, except for possible retransmission requests); 3, measuring code offset (only requires user terminal to listen, no data is transferred); 4, Transmit location file to location center or communication processor 1804 (data links can be either one way or two way). Distance measurement can only be performed by the system and since it requires a two way link it can be done while a normal conversation channel has been established or if the terminal is in the listening mode the system has to establish a short round trip connection.

The two way link is required because the base station measures the code phase difference between the signal it sends to, and the signal it receives from, the user terminal. In FIG. 18 the foregoing function is accomplished in processor 1804. In this sense, the system operates like a radar with a pulse the width of a PN chip. The one way data link message transporting the distance message to the user terminal, is a single message that typically will include an error correcting code, and may also require an acknowledgment message to be sent back from the user terminal to the base station. The acknowledgment message could be sent independently or appended as part of the distance measurement function.

The code offset information is also placed it in a file that is accessible from outside the system. As described previously the user terminal time shares one receiver on the three independent paths that emanate at different times from the three different antennas. Therefore, the receiver tracks three independent paths one after the other. The PN code on each path is the same, and as described above the code has the same starting time at each antenna, but because of the difference in distance to the three different antennas, from the user terminal, the codes arriving at the user terminal are of different code phases. However, since the system cycles very rapidly from antenna to antenna, the receiver cycles between signals received from each of the antennas. Therefore, the receiver maintains three separate starting states and tracking loops for the different time slots. At the end of each time slot, the exact time is known in advance, the previous state is stored in the computer and restored at the beginning of the next time slot assigned to the same antenna. Thus, the processor is emulating three different receivers. The receiver quickly adjusts for any slight drift that occurred while the receiver was locked to the other antennas. Note that the receiver has a specific starting state. Thus, the PN sequence has been shifted to compensate for the difference in range on the path between the user terminal and the first antenna and the path between the user terminal and the second antenna. The difference is the code offset, because the code offset measures the difference in range. Thus, the distance to the second antenna is known without having to do a closed loop (two way) measurement. The same process is followed for the third antenna.

Additional entries, greater than three, in the location file are available using the normal search mode that the user terminal radio uses to identify potential candidates for handoff. The user terminal radio searches the pilot codes emanating from nearby antennas to determine if any of these antennas have better signals than one of the three that are currently being used. If so, the user terminal notifies the system that a good candidate is available. The process of searching starts at the state of the PN signal coming in from time slot number one and if nothing is found at that state the radio adds a chip to the path length and integrates again. The radio keeps adding chips until it finds a signal or exceeds a range threshold. If it exceeds the range threshold it resets the PN generator to a new pilot code and starts at the 0 offset distance again. Therefore, when the radio finds a new pilot signal it knows how many chips it added before it was successful. The added number of chips is also the code offset. The code offset value along with the identity of the code, which uniquely names the antenna, and the time stamp are entered into the location file. The radio places these entries in the location file even if they are not better than the current signals. As the radio scans and finds new antennas it places the four best results in the location file. As it continues to scan, older entries are replaced with newer better entries.

Now that the necessary information is available in the user terminal location file, it may be made available to any authorized requester. Location services may be provided by the communications operator or by a competitive independent service provider. In addition, there will also be large private location centers operated by owners of large fleets. The location center 1902 receives the location files over the public switched network, see FIG. 19. The network can be a circuit switched network or a packet switched network. A packet switched network is adequate and economical for this type of application.

What is claimed is:

1. In a wireless communication system including a time division multiplex signal having first and second time slots, and a code division multiplex signal using PN spread spectrum modulation, a method for communicating a data packet containing digital data from a transmitter to a receiver to form a received data packet, said system including first and second antennas spaced apart from each other, said method comprising:

placing said data packet in said first time slot of said time division multiplex signal;

placing said data packet in said second time slot of said time division multiplex signal;

encoding said first time slot of said time division multiplex signal using said PN spread spectrum modulation to form a first spread spectrum modulated data packet;

encoding said second time slot of said time division multiplex signal using said PN spread spectrum modulation to form a second spread spectrum modulated data packet;

transmitting said first spread spectrum modulated data packet from said first antenna to form a first transmitted data packet;

transmitting said second spread spectrum modulated data packet from said second antenna to form a second transmitted data packet after said first transmitted data packet;

receiving in sequence said first and second transmitted data packets at said receiver forming respective first and second received data packets; and

selecting at least one of said first and second received data packets to form said digital data at said receiver.

2. A method in accordance with claim 1, further including a carrier frequency having a characteristic wavelength, wherein said first and second antennas are spaced apart from each other by a distance between a quarter of said wavelength and ten times said wavelength.

3. A method in accordance with claim 1, wherein said step of selecting at least one of said first and second received data packets to form said digital data at said receiver comprises a step of combining the energy of said received first and second received data packets in a maximal manner.

4. A method in accordance with claim 3, wherein said step of combining the energy of said received first and second received data packets in a maximal manner is to combine the energy of said received first and second data packets in a maximum likelihood combiner.

5. In a wireless communication system including a time division multiplex signal having first, second and third time slots, and a code division multiplex signal using PN spread spectrum modulation, a method for communicating a data packet containing digital data from a transmitter to a receiver to form a received data packet, said system including first, second and third antennas spaced apart from each other, said method comprising:

placing said data packet in said first time slot of said time division multiplex signal;

placing said data packet in said second time slot of said time division multiplex signal;

placing said data packet in said third time slot of said time division multiplex signal;

encoding said first time slot of said time division multiplex signal using said PN spread spectrum modulation to form a first spread spectrum modulated data packet;

encoding said second time slot of said time division multiplex signal using said PN spread spectrum modulation to form a second spread spectrum modulated data packet;

encoding said third time slot of said time division multiplex signal using said PN spread spectrum modulation to form a third spread spectrum modulated data packet;

transmitting said data first spread spectrum modulated packet from said first antenna to form a first transmitted data packet;

transmitting said second spread spectrum modulated data packet from said second antenna to form a second transmitted data packet after said first transmitted data packet;

transmitting said third spread spectrum modulated data packet from said third antenna to form a third transmitted data packet after said second transmitted data packet;

receiving in sequence said first, second and third transmitted data packets at said receiver forming respective first, second and third received data packets; and

selecting at least one of said first, second and third received data packets to form said digital data at said receiver.

6. A method in accordance with claim 5, further including a carrier frequency having a characteristic wavelength, wherein said first, second and third antennas are spaced apart from each other by a distance between a quarter of said wavelength and ten times said wavelength.

7. A method in accordance with claim 5, wherein said step of selecting at least one of said first, second and third received data packets to form said digital data at said receiver comprises a step of combining the energy of said received first, second and third received data packets in a maximal manner.

8. A method in accordance with claim 7, wherein said step of combining the energy of said received first, second and third received data packets in a maximal manner is to combine the energy of said received first, second and third data packets in a maximum likelihood combiner.

9. In a wireless communication system, wherein a data packet is communicated from a base station to a subscriber station, said system including at least one transfer station between said base station and said subscriber station for receiving said data packet from said base station and retransmitting said data packet to said subscriber station on a first antenna to form a first transmitted data packet and retransmitting said data packet on a second antenna to form a second transmitted data packet after said first transmitted data packet, a method in a receiver in said subscriber station for receiving said data packet, said method comprising:

receiving said first transmitted data packet at said subscriber station receiver forming said first received data packet;

receiving said second transmitted data packet at said subscriber station receiver forming respective second received data packet after receiving said first transmitted data packet;

selecting at least one of said first and second received data packets to form said received data packet at said receiver,

wherein said data packet is communicated from said base station to said transfer station by a time division multiplex signal, and said data packet is retransmitted from said transfer station to said subscriber station by a code division multiplex signal, said code division multiplex signal being divided into first and second time slots containing said first transmitted data packet and said second transmitted data packet, respectively.

10. A method in accordance with claim 9, further comprising the step of selecting one of said first and second data packets based in part on the first and second data packet having the least bit error rate.

11. A method in accordance with claim 9, further comprising the step of selecting one of said first and second data packets based in part on the first and second data packet having the least bit phase distortion.

12. A method in accordance with claim 9, further comprising the step of selecting one of said first and second data packets based in part on the first and second data packet having the highest signal to noise ratio.

13. A method in accordance with claim 9, further including retransmitting said data packet on a third antenna to form a third transmitted data packet after said second transmitted data packet, wherein said code division multiplex signal is further divided into a third time slot containing said third transmitted data packet.

14. A method in accordance with claim 9, wherein said subscriber station further includes an antenna and a

transmitter, and wherein said subscriber station method further includes the step of switching said antenna between said receiver for receiving said data packet and said transmitter.

15. In a wireless communication system including a time division multiplex signal having first and second time slots, and a code division multiplex signal using PN spread spectrum modulation, an apparatus for communicating a data packet containing digital data from a transmitter to a receiver to form a received data packet, said system including first and second antennas spaced apart from each other, said apparatus comprising:

means for placing said data packet in said first time slot of said time division multiplex signal;

means for placing said data packet in said second time slot of said time division multiplex signal;

means for encoding said first time slot of said time division multiplex signal using said PN spread spectrum modulation to form a first spread spectrum modulated data packet;

means for encoding said second time slot of said time division multiplex signal using said PN spread spectrum modulation to form a second spread spectrum modulated data packet;

means for transmitting said first spread spectrum modulated data packet from said first antenna to form a first transmitted data packet;

means for transmitting said second spread spectrum modulated data packet from said second antenna to form a second transmitted data packet after said first transmitted data packet;

means for receiving in sequence said first and second transmitted data packets at said receiver forming respective first and second received data packets; and

means for selecting at least one of said first and second received data packets to form said digital data at said receiver.

16. An apparatus in accordance with claim 15, further including a carrier frequency having a characteristic wavelength, wherein said first and second antennas are spaced apart from each other by a distance between a quarter of said wavelength and ten times said wavelength.

17. An apparatus in accordance with claim 15, wherein said means for selecting at least one of said first and second received data packets to form said digital data at said receiver comprises a means for combining the energy of said received first and second received data packets in a maximal manner.

18. An apparatus in accordance with claim 17, wherein said means for combining the energy of said received first and second received data packets in a maximal manner is to combine the energy of said received first and second data packets in a maximum likelihood combiner.

19. In a wireless communication system including a time division multiplex signal having first, second and third time slots, and a code division multiplex signal using PN spread spectrum modulation, an apparatus for communicating a data packet containing digital data from a transmitter to a receiver to form a received data packet, said system including first, second and third antennas spaced apart from each other, said apparatus comprising:

means for placing said data packet in said first time slot of said time division multiplex signal;

means for placing said data packet in said second time slot of said time division multiplex signal;

means for placing said data packet in said third time slot of said time division multiplex signal;

means for encoding said first time slot of said time division multiplex signal using said PN spread spectrum modulation to form a first spread spectrum modulated data packet;

means for encoding said second time slot of said time division multiplex signal using said PN spread spectrum modulation to form a second spread spectrum modulated data packet;

means for encoding said third time slot of said time division multiplex signal using said PN spread spectrum modulation to form a third spread spectrum modulated data packet;

means for transmitting said first spread spectrum modulated data packet from said first antenna to form a first transmitted data packet;

means for transmitting said second spread spectrum modulated data packet from said second antenna to form a second transmitted data packet after said first transmitted data packet;

means for transmitting said third spread spectrum modulated data packet from said third antenna to form a third transmitted data packet after said second transmitted data packet;

means for receiving in sequence said first, second and third transmitted data packets at said receiver forming respective first, second and third received data packets; and

means for selecting at least one of said first, second and third received data packets to form said digital data at said receiver.

20. An apparatus in accordance with claim 19, further including a carrier frequency having a characteristic wavelength, wherein said first, second and third antennas are spaced apart from each other by a distance between a quarter of said wavelength and ten times said wavelength.

21. An apparatus in accordance with claim 19, wherein said means for selecting at least one of said first, second and third received data packets to form said digital data at said receiver comprises a means for combining the energy of said received first, second and third received data packets in a maximal manner.

22. An apparatus in accordance with claim 21, wherein said means for combining the energy of said received first, second and third received data packets in a maximal manner is to combine the energy of said received first, second and third data packets in a maximum likelihood combiner.

23. In a wireless communication system, wherein a data packet is communicated from a base station to a subscriber station, said system including at least one transfer station between said base station add said subscriber station for receiving said data packet from said base station and retransmitting said data packet to said subscriber station on a first antenna to form a first transmitted data packet and retransmitting said data packet on a second antenna to form a second transmitted data packet after said first transmitted data packet, an apparatus in a receiver in said subscriber station for receiving said data packet, said apparatus comprising:

means for receiving said first transmitted data packet at said subscriber station receiver forming said first received data packet;

means for receiving said second transmitted data packet at said subscriber station receiver forming respective sec-

ond received data packet after receiving said first transmitted data packet;

means for selecting at least one of said first and second received data packets to form said received data packet at said receiver,

wherein said data packet is communicated from said base station to said transfer station by a time division multiplex signal, and said data packet is retransmitted from said transfer station to said subscriber station by a code division multiplex signal, said code division multiplex signal being divided into first and second time slots containing said first transmitted data packet and said second transmitted data packet, respectively.

24. An apparatus in accordance with claim 23, further comprising the means for selecting one of said first and second data packets based in part on the first and second data packet having the least bit error rate.

25. An apparatus in accordance with claim 23, further comprising the means for selecting one of said first and second data packets based in part on the first and second data packet having the least bit phase distortion.

26. An apparatus in accordance with claim 23, further comprising the means for selecting one of said first and second data packets based in part on the first and second data packet having the highest signal to noise ratio.

27. An apparatus in accordance with claim 23, further including retransmitting said data packet on a third antenna to form a third transmitted data packet after said second transmitted data packet, wherein said code division multiplex signal is further divided into a third time slot containing said third transmitted data packet.

28. An apparatus in accordance with claim 23, wherein said subscriber station further includes an antenna and a transmitter, and wherein said subscriber station apparatus further includes the means for switching said antenna between said receiver for receiving said data packet and said transmitter.

29. In a CDMA cellular system that utilizes transmission diversity by transmitting a plurality of time slotted PN spread spectrum signals from a plurality of antennas, a method for communicating a PN spread spectrum modulated data packet containing digital data from a transmitter to a receiver to form a received data packet, said system including at least first and second antennas spaced apart from each other, said method comprising:

transmitting said PN spread spectrum modulated data packet from said first antenna to form a first transmitted PN spread spectrum modulated data packet;

transmitting said PN spread spectrum modulated data packet from said second antenna to form a second transmitted PN spread spectrum modulated data packet after said first PN spread spectrum modulated data packet;

receiving in sequence said first and second PN spread spectrum modulated data packets at said receiver, despreading and demodulating respective PN spread spectrum modulated data packets to form respective received first and second data packets; and

selecting at least one of said first and second received data packets to form said digital data at said receiver,

wherein the time slotted PN spread spectrum signals are TDMA slotted PN spread spectrum modulated data packets, wherein the TDMA time slotted PN spread spectrum modulated data packets are transmitted from said first antenna, and wherein the TDMA time slotted PN spread spectrum modulated data packets transmitted from the said second antenna are off-set in time from the TDMA time slotted PN spread spectrum modulated data packets transmitted from the said first antenna by a time delay of one TDMA time slot.

30. A method in accordance with claim 29, wherein each different data packet from digital data destined for a different receiver is assigned a different and unique PN code the TDMA PN spread spectrum modulated data packet transmitted from said first and second antennas is spread with a different PN spread spectrum modulation than the TDMA PN spread spectrum modulated data packet transmitted to any other receiver.

31. A method in accordance with claim 30, wherein the receive PN spread spectrum despreading and demodulating discriminates against all other PN spread spectrum modulated data packets.

32. In a CDMA cellular system that utilizes transmission diversity by transmitting a plurality of time slotted PN spread spectrum signals from a plurality of antennas, a method for communicating a PN spread spectrum modulated data packet containing digital data from a transmitter to a receiver to form a received data packet, said system including at least first second and third antennas spaced apart from each other, said method comprising:

transmitting said PN spread spectrum modulated data packet from said first antenna to form a first transmitted PN spread spectrum modulated data packet;

transmitting said PN spread spectrum modulated data packet from said second antenna to form a second transmitted PN spread spectrum modulated data packet after said first PN spread spectrum modulated data packet;

transmitting said PN spread spectrum modulated data packet from said third antenna to form a third transmitted PN spread spectrum modulated data packet after second PN spread spectrum modulated packet;

receiving in sequence said first second and third PN spread spectrum modulated data packets at said receiver, despreading and demodulating respective PN spread spectrum modulated data packets to form respective received first, second and third data packets; and

selecting at least one of said first, second and third received data packets to form said digital data at said receiver,

wherein the time slotted PN spread spectrum signals are TDMA slotted PN spread spectrum modulated data packets, wherein the TDMA time slotted PN spread spectrum modulated data packets are transmitted from said second antenna and wherein the TDMA time slotted PN spread spectrum modulated data packets transmitted from the said second antenna are off-set in time from the TDMA time slotted PN spread spectrum modulated data packets transmitted from the said first antenna by a time delay of one CDMA time slot.

33. In a CDMA cellular system that utilizes transmission diversity by transmitting a plurality of time slotted PN spread spectrum signals from a plurality of antennas, a method for communicating a PN spread spectrum modulated data packet containing digital data from a transmitter to a receiver to form a received data packet, said system including at least first second and third antennas spaced apart from each other, said method comprising:

transmitting said PN spread spectrum modulated data packet from said first antenna to form a first transmitted PN spread spectrum modulated data packet;

transmitting said PN spread spectrum modulated data packet from said second antenna to form a second

transmitted PN spread spectrum modulated data packet after said first PN spread spectrum modulated data packet;

transmitting said PN spread spectrum modulated data packet from said third antenna to form a third transmitted PN spread spectrum modulated data packet after second PN spread spectrum modulated packet;

receiving in sequence said first second and third PN spread spectrum modulated data packets at said receiver, despreading and demodulating respective PN spread spectrum modulated data packets to form respective received first, second and third data packets; and

selecting at least one of said first, second and third received data packets to form said digital data at said receiver,

wherein the time slotted PN spread spectrum signals are TDMA slotted PN spread spectrum modulated data packets, wherein the TDMA time slotted PN spread spectrum modulated data packets are transmitted from said third antenna and wherein the TDMA time slotted PN spread spectrum modulated data packets transmitted from the said third antenna are off-set in time from the TDMA time slotted PN spread spectrum modulated data packets transmitted from the said first antenna by a time delay of at least two TDMA time slots.

34. In a CDMA cellular system that utilizes transmission diversity by transmitting a plurality of time slotted PN spread spectrum signals from a plurality of antennas, an apparatus for communicating a PN spread spectrum modulated data packet containing digital data from a transmitter to a receiver to form a received data packet, said system including at least first and second antennas spaced apart from each other, said apparatus comprising:

means for transmitting said PN spread spectrum modulated data packet from said first antenna to form a first transmitted PN spread spectrum modulated data packet;

means for transmitting said PN spread spectrum modulated data packet from said second antenna to form a second transmitted PN spread spectrum modulated data packet after said first PN spread spectrum modulated data packet;

means for receiving in sequence said first and second PN spread spectrum modulated data packets at said receiver, despreading and demodulating respective PN spread spectrum modulated data packets to form respective received first and second data packets; and

means for selecting at least one of said first and second received data packets to form said digital data at said receiver,

wherein the time slotted PN spread spectrum signals are TDMA slotted PN spread spectrum modulated data packets, wherein the TDMA time slotted PN spread spectrum modulated data packets are transmitted from said first antenna and wherein the TDMA time slotted PN spread spectrum modulated data packets transmitted from the said second antenna are off-set in time from the TDMA time slotted PN spread spectrum modulated data packets transmitted from the said first antenna by a time delay of one TDMA time slot.

35. An apparatus in accordance with claim 34, wherein each different data packet from digital data destined for a different receiver is assigned a different and unique PN code the TDMA PN spread spectrum modulated data packet transmitted from said first and second antennas is spread with a different PN spread spectrum modulation than the

TDMA PN spread spectrum modulated data packet transmitted to any other receiver.

36. An apparatus in accordance with claim 35, wherein the receive PN spread spectrum despreading and demodulating discriminates against all other PN spread spectrum modulated data packets.

37. In a CDMA cellular system that utilizes transmission diversity by transmitting a plurality of time slotted PN spread spectrum signals from a plurality of antennas, an apparatus for communicating a PN spread spectrum modulated data packet containing digital data from a transmitter to a receiver to form a received data packet, said system including at least first second and third antennas spaced apart from each other, said apparatus comprising:

means for transmitting said PN spread spectrum modulated data packet from said first antenna to form a first transmitted PN spread spectrum modulated data packet;

means for transmitting said PN spread spectrum modulated data packet from said second antenna to form a second transmitted PN spread spectrum modulated data packet after said first PN spread spectrum modulated data packet;

means for transmitting said PN spread spectrum modulated data packet from said third antenna to form a third transmitted PN spread spectrum modulated data packet after second PN spread spectrum modulated packet;

means for receiving in sequence said first second and third PN spread spectrum modulated data packets at said receiver, despreading and demodulating respective PN spread spectrum modulated data packets to form respective received first, second and third data packets; and

means for selecting at least one of said first, second and third received data packets to form said digital data at said receiver,

wherein the time slotted PN spread spectrum signals are TDMA slotted PN spread spectrum modulated data packets, wherein the TDMA time slotted PN spread spectrum modulated data packets are transmitted from said second antenna and wherein the TDMA time slotted PN spread spectrum modulated data packets transmitted from the said second antenna are off-set in time from the TDMA time slotted PN spread spectrum modulated data packets transmitted from the said first antenna by a time delay of one CDMA time slot.

38. In a CDMA cellular system that utilizes transmission diversity by transmitting a plurality of time slotted PN spread spectrum signals from a plurality of antennas, an apparatus for communicating a PN spread spectrum modulated data packet containing digital data from a transmitter to a receiver to form a received data packet, said system including at least first second and third antennas spaced apart from each other, said apparatus comprising:

means for transmitting said PN spread spectrum modulated data packet from said first antenna to form a first transmitted PN spread spectrum modulated data packet;

means for transmitting said PN spread spectrum modulated data packet from said second antenna to form a second transmitted PN spread spectrum modulated data packet after said first PN spread spectrum modulated data packet;

means for transmitting said PN spread spectrum modulated data packet from said third antenna to form a third transmitted PN spread spectrum modulated data packet after second PN spread spectrum modulated packet;

means for receiving in sequence said first second and third PN spread spectrum modulated data packets at said receiver, despreading and demodulating respective PN spread spectrum modulated data packets to form respective received first, second and third data packets; and

means for selecting at least one of said first, second and third received data packets to form said digital data at said receiver,

wherein the time slotted PN spread spectrum signals are TDMA slotted PN spread spectrum modulated data packets,

wherein the TDMA time slotted PN spread spectrum modulated data packets are transmitted from said third antenna and wherein the TDMA time slotted PN spread spectrum modulated data packets transmitted from the said third antenna are off-set in time from the TDMA time slotted PN spread spectrum modulated data packets transmitted from the said first antenna by a time delay of at least two TDMA time slots.

* * * * *

EXHIBIT 6

US005859879A

United States Patent [19]

Bolgiano et al.

[11] Patent Number: 5,859,879

[45] Date of Patent: Jan. 12, 1999

[54] WIRELESS TELEPHONE DISTRIBUTION SYSTEM WITH TIME AND SPACE DIVERSITY TRANSMISSION

[75] Inventors: D. Ridgely Bolgiano, Gladwyne, Pa.; Gilbert E LaVean, Reston, Va.

[73] Assignee: Interdigital Technology Corporation, Wilmington, Del.

[21] Appl. No.: 920,781

[22] Filed: Aug. 29, 1997

Related U.S. Application Data

[60] Continuation of Ser. No. 538,863, Oct. 4, 1995, Pat. No. 5,663,990, which is a division of Ser. No. 301,230, Sep. 6, 1994, Pat. No. 5,614,914.

[51] Int. Cl.[6] H04B 7/10; H04L 1/02

[52] U.S. Cl. 375/347; 375/205; 375/206; 455/101

[58] Field of Search 375/347, 206, 375/205; 455/59, 60, 61, 101

[56] References Cited

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5,781,541	7/1998	Schneider	370/335

Primary Examiner—Stephen Chin
Assistant Examiner—Mohammad Gheyour
Attorney, Agent, or Firm—Allan Jacobson

[57] ABSTRACT

A wireless communication system combines time and space diversity to reduce fading and simplify receiver design. In particular, a data packet which carries digital telephone traffic, is transmitted at three different times from three different antennas. The mobile subscriber receiver thus receives the same data packet at three different times from three different antennas, and uses the best data packet or combination of the data packets to reduce the effects of fading. A transfer station receives a time division multiplex multiple access (TDMA) signal from a base station carrying telephone data packet traffic to form three data packet repeats at spatially diverse antennas locations. The transfer station further modulates a code division multiple access (CDMA) system using a TDMA signal which links the mobile subscriber receiver to the transfer station. Each data packet received at the transfer station is thus retransmitted at three different times to the mobile subscriber station on a CDMA link.

64 Claims, 19 Drawing Sheets

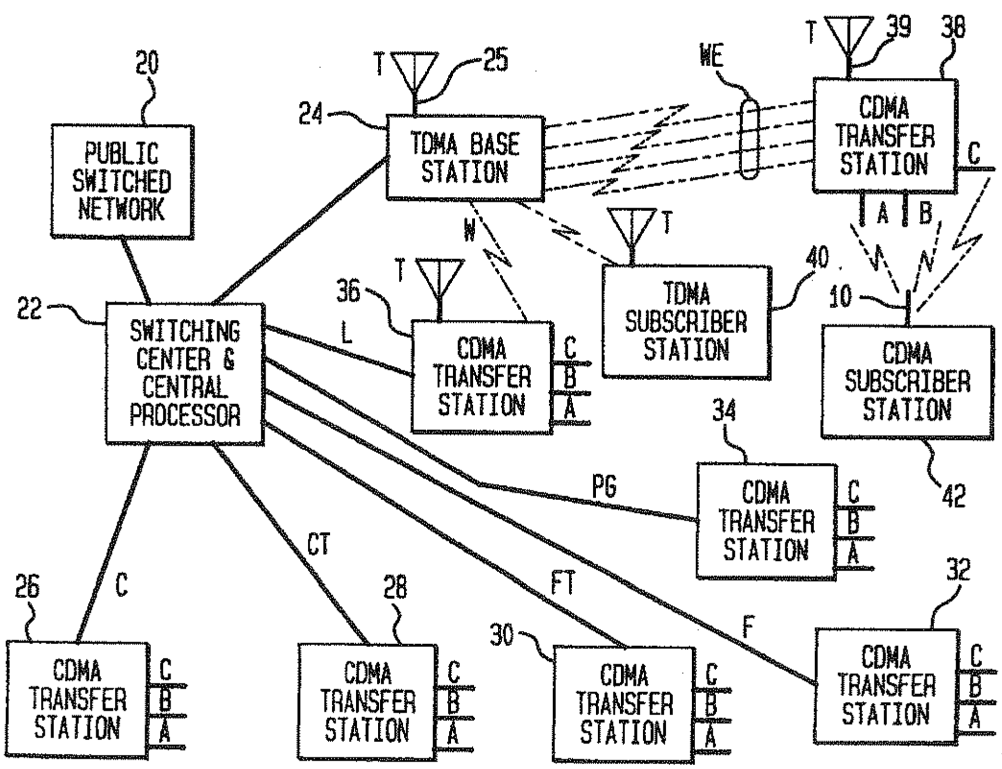


FIG. 1

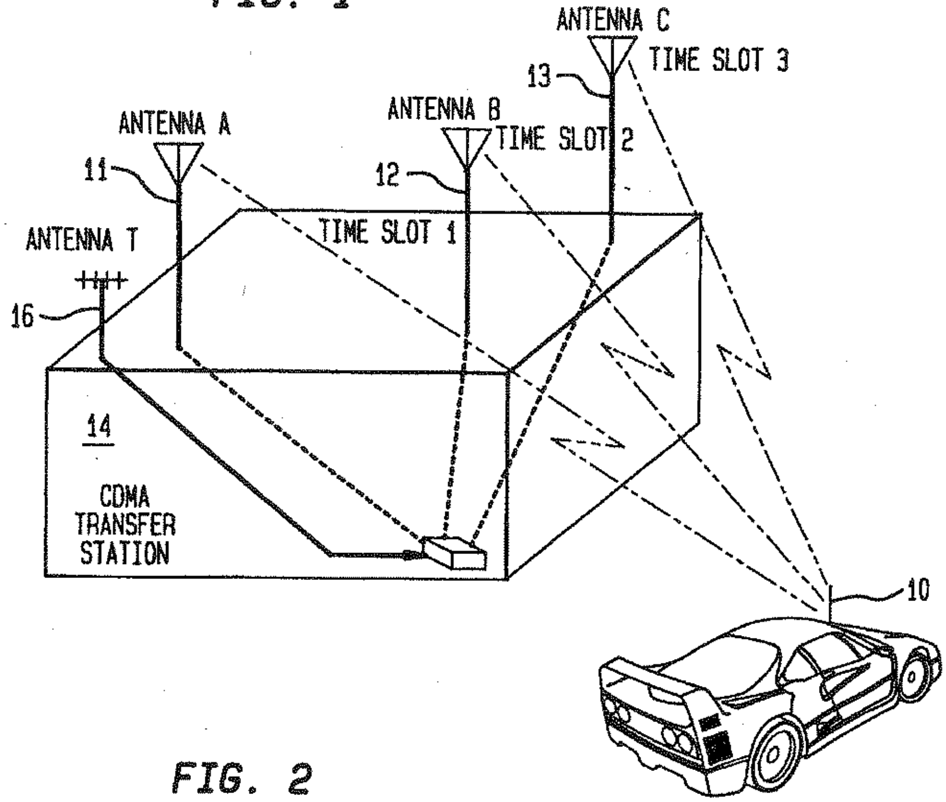

ANTENNA C
TIME SLOT 3
13
ANTENNA B
TIME SLOT 2
ANTENNA A
11
12
ANTENNA T
TIME SLOT 1
16
14
CDMA TRANSFER STATION
10

FIG. 2

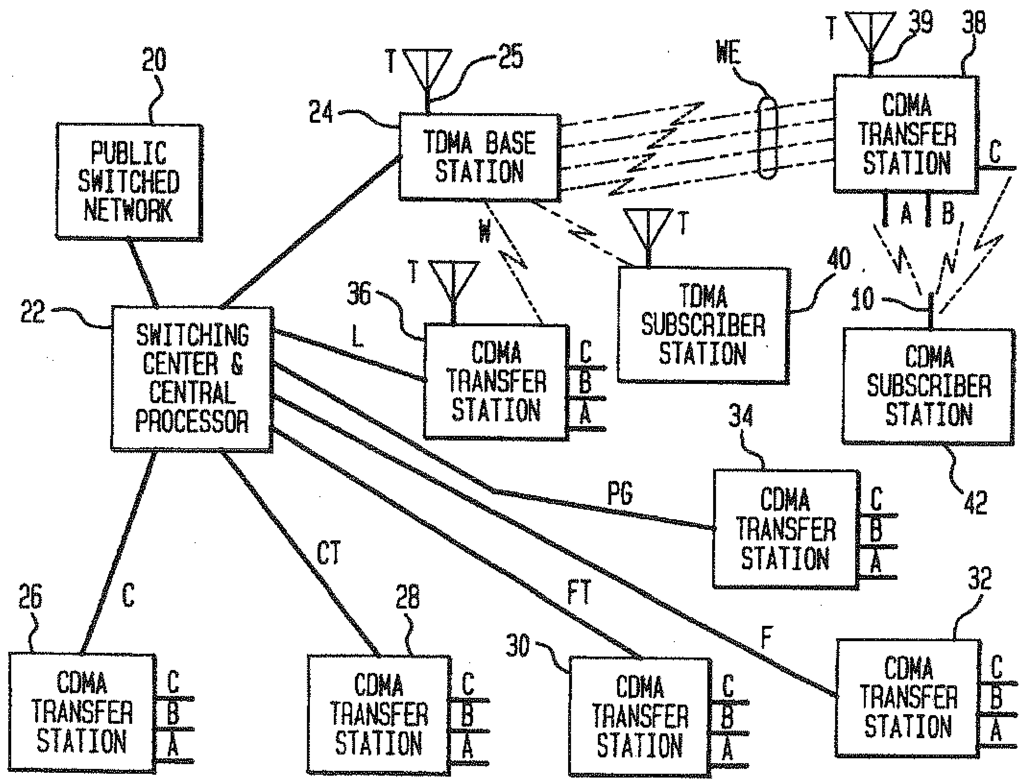
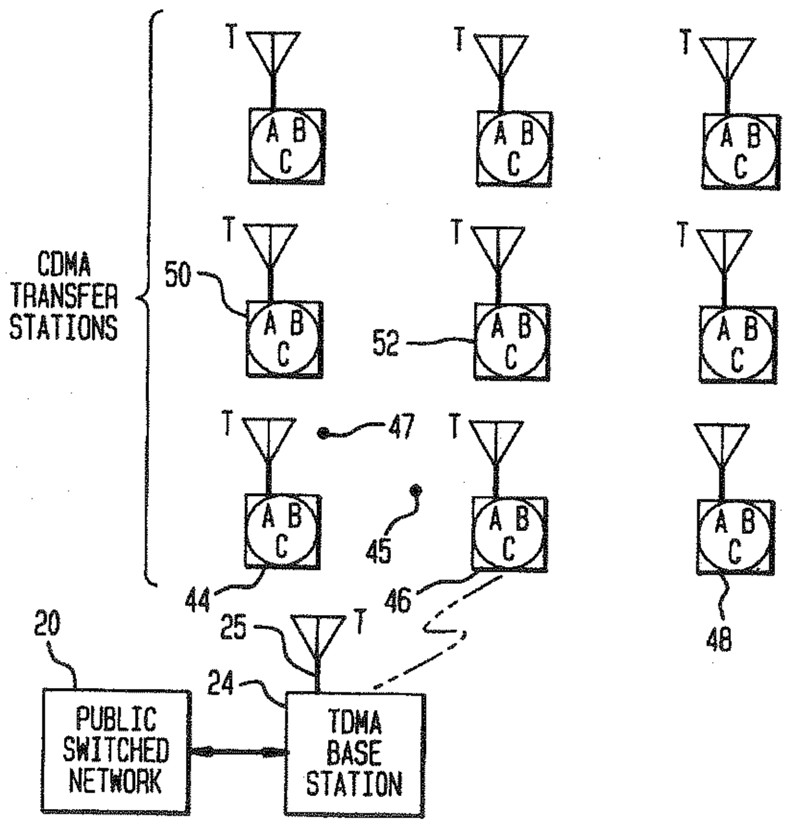

20
PUBLIC SWITCHED NETWORK
T
25
24
TDMA BASE STATION
WE
T
39
38
CDMA TRANSFER STATION
C
A
B
W
T
TDMA SUBSCRIBER STATION
40
10
22
SWITCHING CENTER & CENTRAL PROCESSOR
36
T
L
CDMA TRANSFER STATION
C
B
A
CDMA SUBSCRIBER STATION
42
34
PG
CDMA TRANSFER STATION
CT
FT
F
32
26
C
28
30
CDMA TRANSFER STATION

FIG. 3



CDMA TRANSFER STATIONS
T
A B C
50
52
47
45
44
46
48
20
25
24
PUBLIC SWITCHED NETWORK
TDMA BASE STATION

FIG. 4

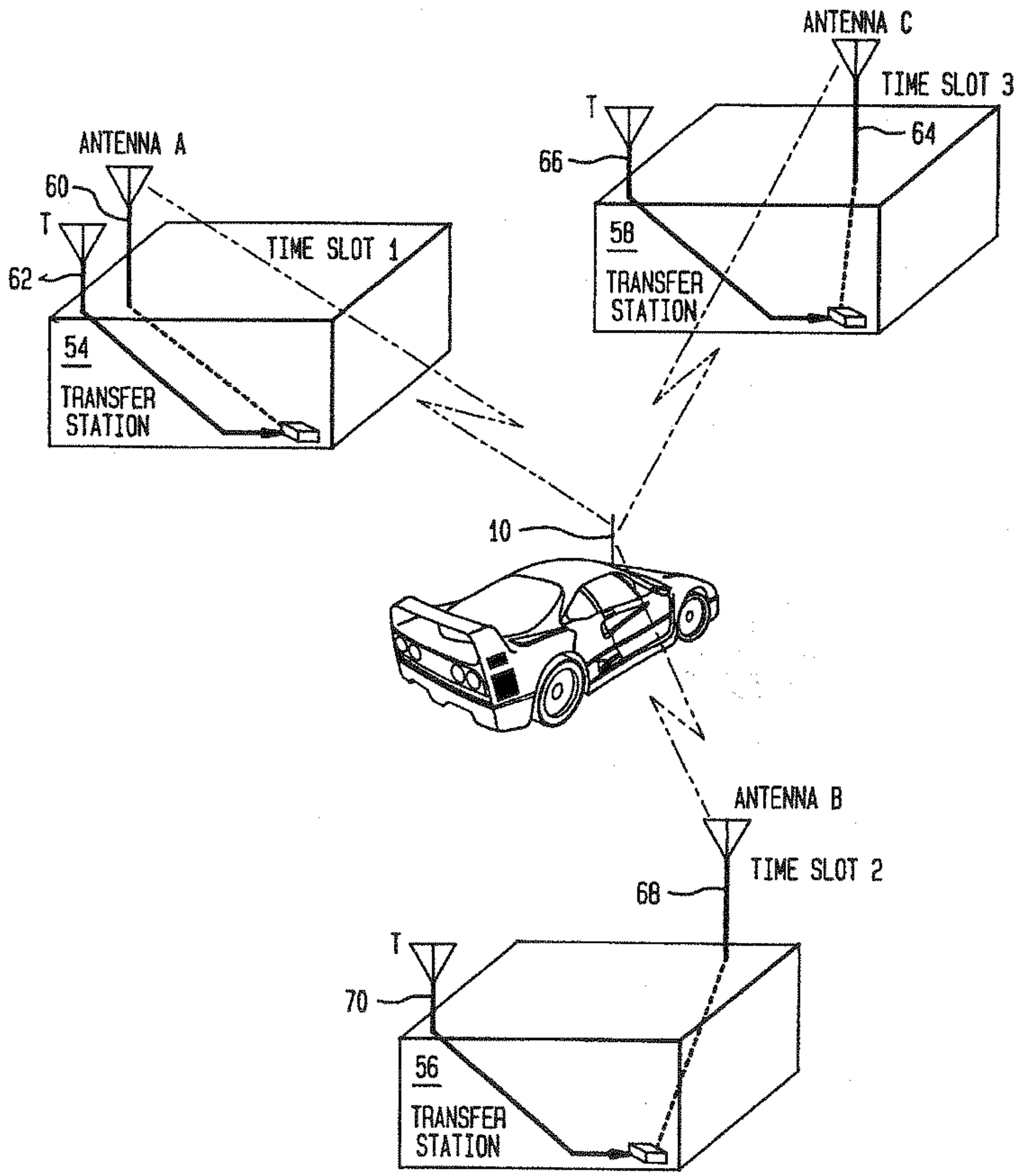
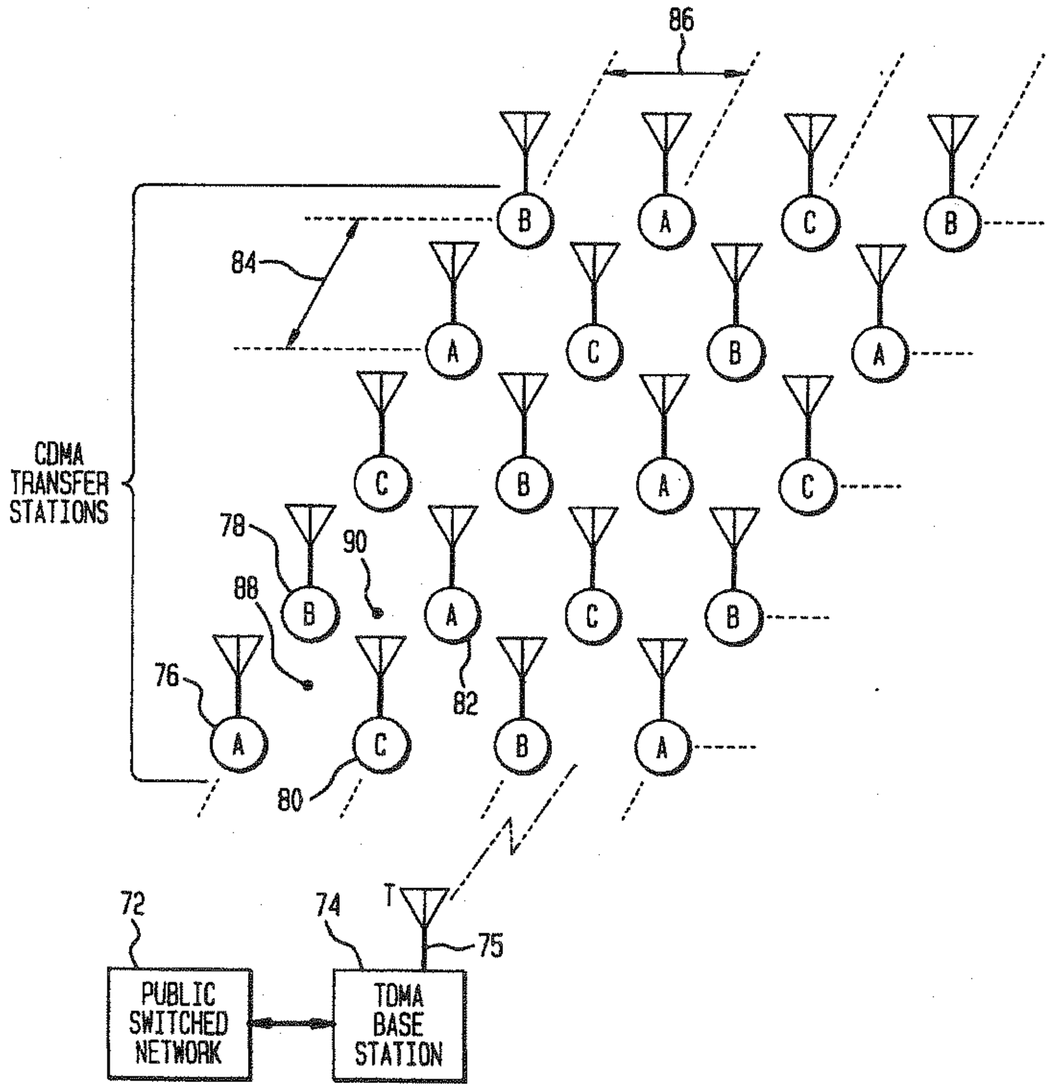

ANTENNA C
TIME SLOT 3
T
64
66
58
TRANSFER STATION
ANTENNA A
60
T
62
TIME SLOT 1
54
TRANSFER STATION
10
ANTENNA B
TIME SLOT 2
68
T
70
56
TRANSFER STATION

FIG. 5



86
84
CDMA
TRANSFER
STATIONS
B
A
C
B
A
C
B
A
C
B
A
C
78
90
88
B
A
C
B
76
A
C
82
B
A
80
72
74
T
75
PUBLIC
SWITCHED
NETWORK
TDMA
BASE
STATION

FIG. 6

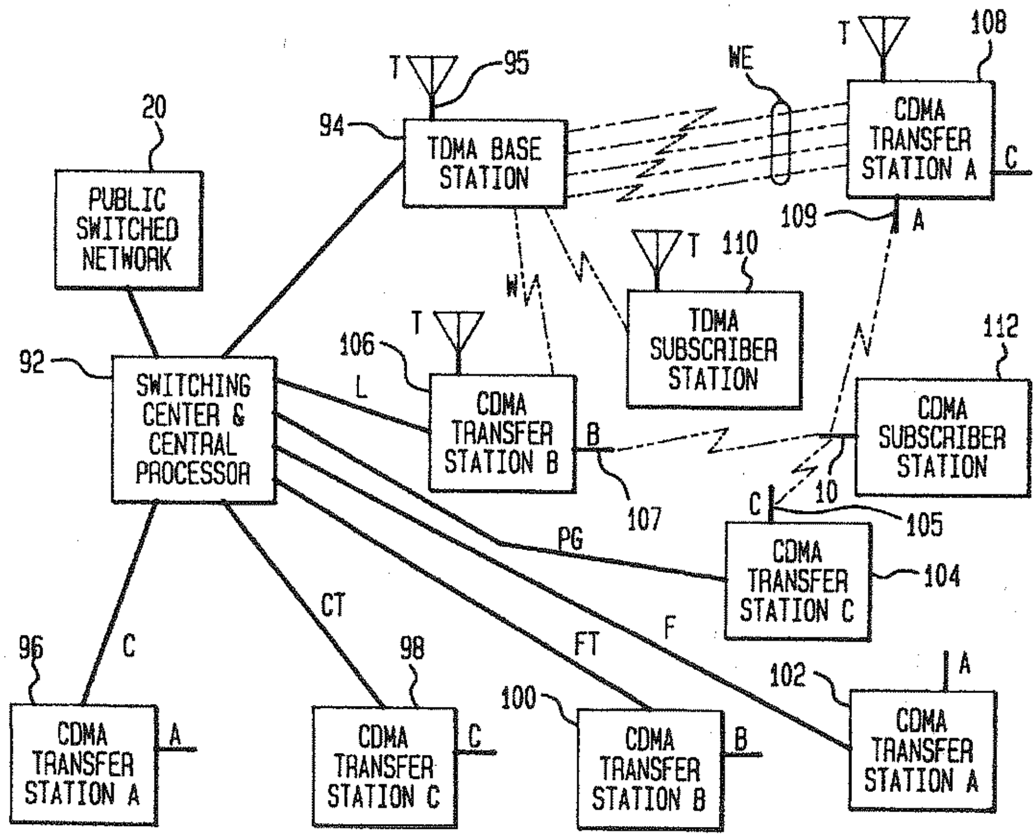


FIG. 7

TIME SLOTS	1	2	3	4	5	6
	RECEIVE	RECEIVE	TRANSMIT	RECEIVE	SCAN	SPARE

FIG. 8

TRANSFER STATION FORWARD CHANNEL

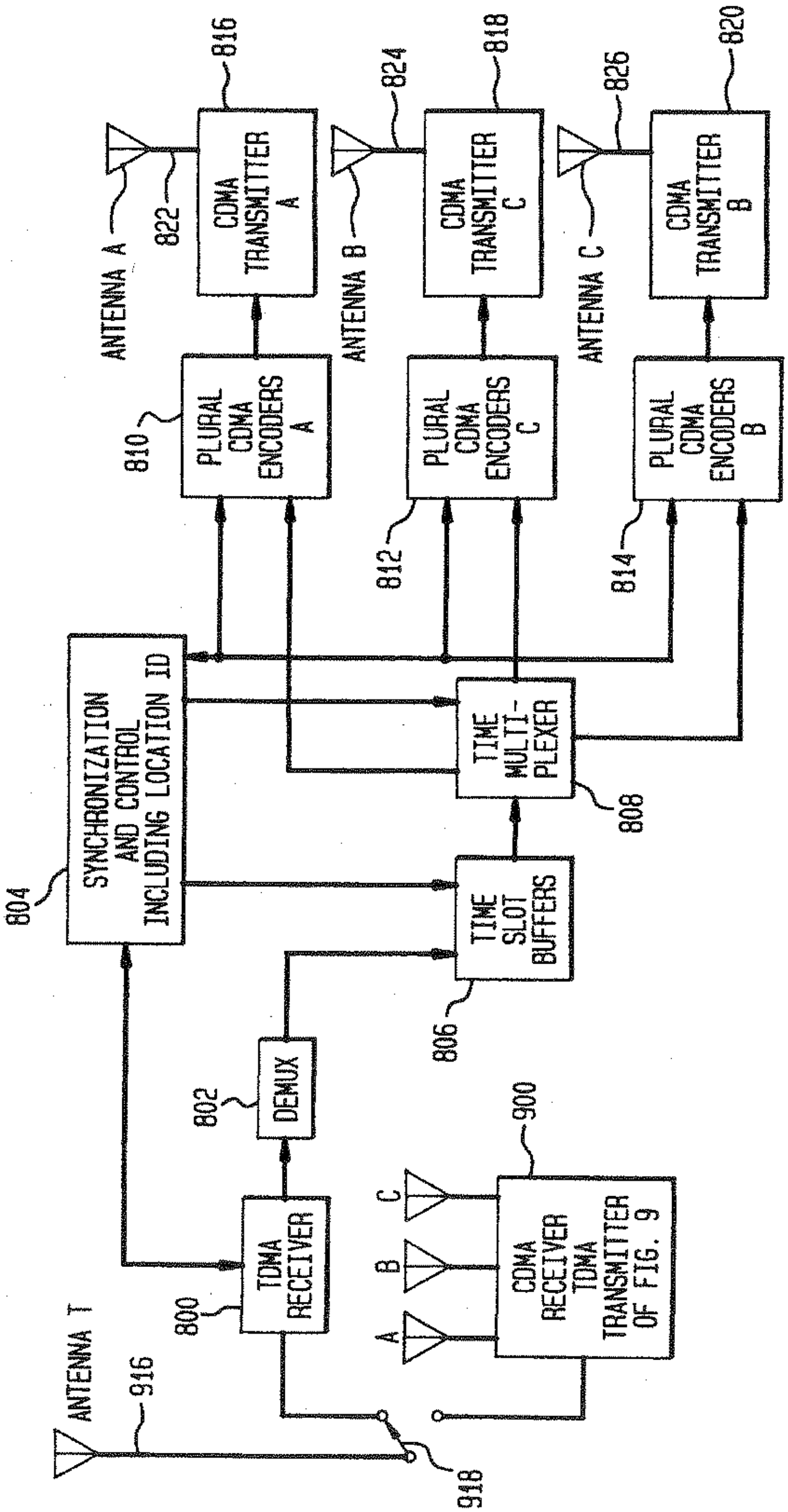


FIG. 9

TRANSFER STATION REVERSE CHANNEL

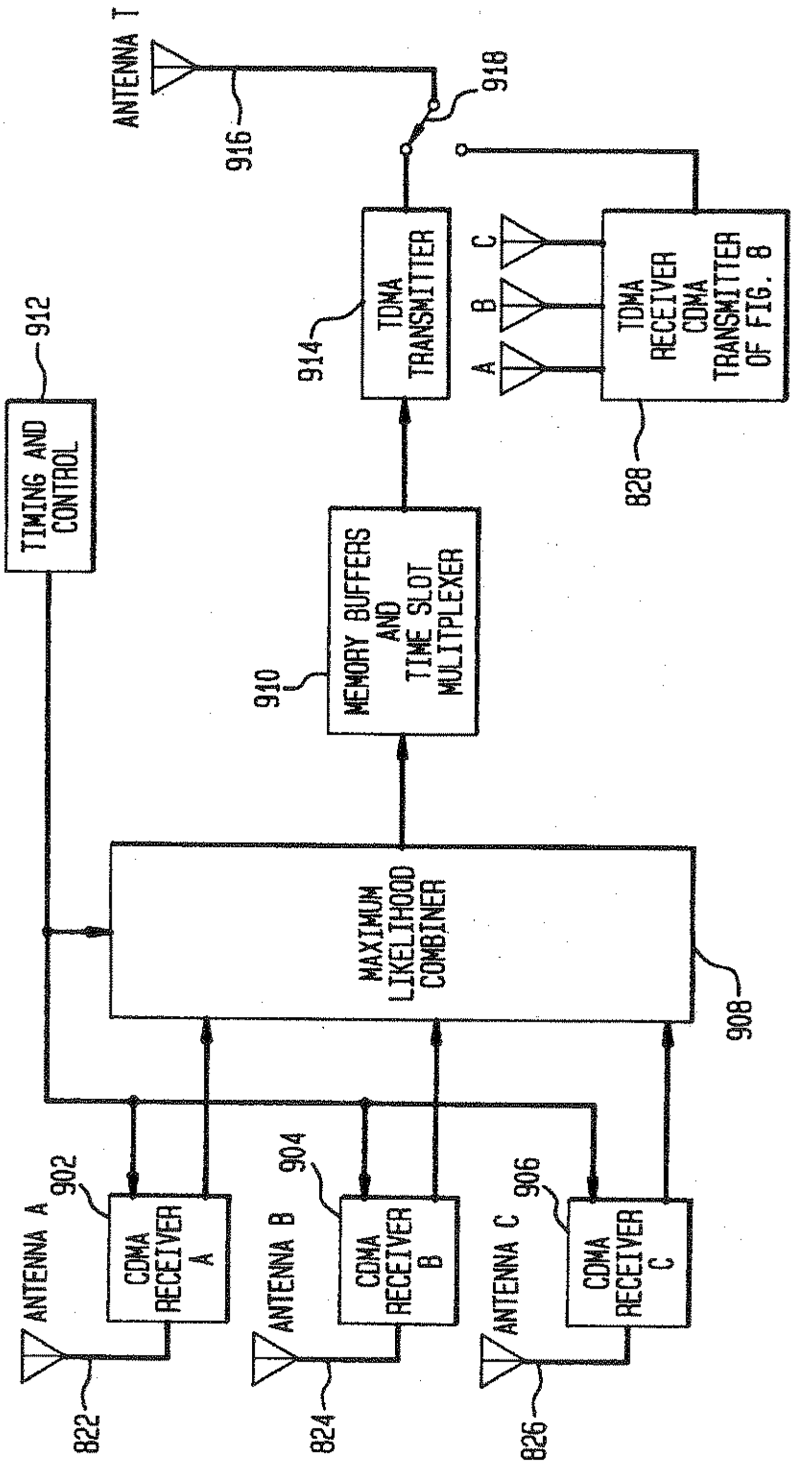


FIG. 10A

TRANSFER STATION CDMA OUTPUT TO ANTENNAS (FORWARD CHANNEL)

TIME SLOTS	1	2	3	4	5	6	1	2
ANTENNA A	T_1	T_2	T_3	T_4	T_5	T_6	T_1	T_2
ANTENNA B	T_6	T_1	T_2	T_3	T_4	T_5	T_6	T_1
ANTENNA C	T_4	T_5	T_6	T_1	T_2	T_3	T_4	T_5

1002

TRANSFER STATION CDMA INPUT FROM ANTENNAS (REVERSE CHANNEL)

TIME SLOTS	1	2	3	4	5	6	1	2
ANTENNA A	R_5	R_6	R_1	R_2	R_3	R_4	R_5	R_6
ANTENNA B	R_5	R_6	R_1	R_2	R_3	R_4	R_5	R_6
ANTENNA C	R_5	R_6	R_1	R_2	R_3	R_4	R_5	R_6

1004

T_X = TRANSMITTER CHANNEL X R_X = RECEIVER CHANNEL X

FIG. 10B

TRANSFER STATION CDMA OUTPUT TO ANTENNAS (FORWARD CHANNEL)

TIME SLOTS	1	2	3	4	5	6	1	2
ANTENNA A	$T_{1,7}$	$T_{2,8}$	$T_{3,9}$	$T_{4,10}$	$T_{5,11}$	$T_{6,12}$	$T_{1,7}$	$T_{2,8}$
ANTENNA B	$T_{6,12}$	$T_{1,7}$	$T_{2,8}$	$T_{3,9}$	$T_{4,10}$	$T_{5,11}$	$T_{6,12}$	$T_{1,7}$
ANTENNA C	$T_{4,10}$	$T_{5,11}$	$T_{6,12}$	$T_{1,7}$	$T_{2,8}$	$T_{3,9}$	$T_{4,10}$	$T_{5,11}$

1006

TRANSFER STATION CDMA INPUT FROM ANTENNAS (REVERSE CHANNEL)

TIME SLOTS	1	2	3	4	5	6	1	2
ANTENNA A	$R_{5,11}$	$R_{6,12}$	$R_{1,7}$	$R_{2,8}$	$R_{3,9}$	$R_{4,10}$	$R_{5,11}$	$R_{6,12}$
ANTENNA B	$R_{5,11}$	$R_{6,12}$	$R_{1,7}$	$R_{2,8}$	$R_{3,9}$	$R_{4,10}$	$R_{5,11}$	$R_{6,12}$
ANTENNA C	$R_{5,11}$	$R_{6,12}$	$R_{1,7}$	$R_{2,8}$	$R_{3,9}$	$R_{4,10}$	$R_{5,11}$	$R_{6,12}$

1008

T_X = TRANSMITTER CHANNEL X R_X = RECEIVER CHANNEL X

$T_{X,Y}$ = TRANSMITTER CHANNELS X AND Y $R_{X,Y}$ = RECEIVER CHANNELS X AND Y

FIG. 11A

TRANSFER STATION CDMA OUTPUT TO ANTENNAS (FORWARD CHANNEL)

TIME SLOTS	1	2	3	4	5	6	1	2	
ANTENNA A	T_1	T_2	T_3	T_4	T_5	T_6	T_1	T_2	
	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}	T_7	T_8	1102
	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{13}	T_{14}	
	T_{19}	T_{20}	T_{21}	T_{22}	T_{23}	T_{24}	T_{19}	T_{20}	

TIME SLOTS	1	2	3	4	5	6	1	2	
ANTENNA B	T_6	T_1	T_2	T_3	T_4	T_5	T_6	T_1	
	T_{12}	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}	T_7	1104
	T_{18}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{13}	
	T_{24}	T_{19}	T_{20}	T_{21}	T_{22}	T_{23}	T_{24}	T_{19}	

TIME SLOTS	1	2	3	4	5	6	1	2	
ANTENNA C	T_4	T_5	T_6	T_1	T_2	T_3	T_4	T_5	
	T_{10}	T_{11}	T_{12}	T_7	T_8	T_9	T_{10}	T_{11}	1106
	T_{16}	T_{17}	T_{18}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	
	T_{22}	T_{23}	T_{24}	T_{19}	T_{20}	T_{21}	T_{22}	T_{23}	

FIG. 11B

TRANSFER STATION CDMA INPUT FROM ANTENNAS (REVERSE CHANNEL)

	1	2	3	4	5	6	1	2	
ANTENNA A, ANTENNA B AND ANTENNA C HAVE IDENTICAL TIME SLOTTING	R_5	R_6	R_1	R_2	R_3	R_4	R_5	R_6	
	R_{11}	R_{12}	R_7	R_8	R_9	R_{10}	R_{11}	R_{12}	1108
	R_{17}	R_{18}	R_{13}	R_{14}	R_{15}	R_{16}	R_{17}	R_{18}	
	R_{23}	R_{24}	R_{19}	R_{20}	R_{21}	R_{22}	R_{23}	R_{24}	

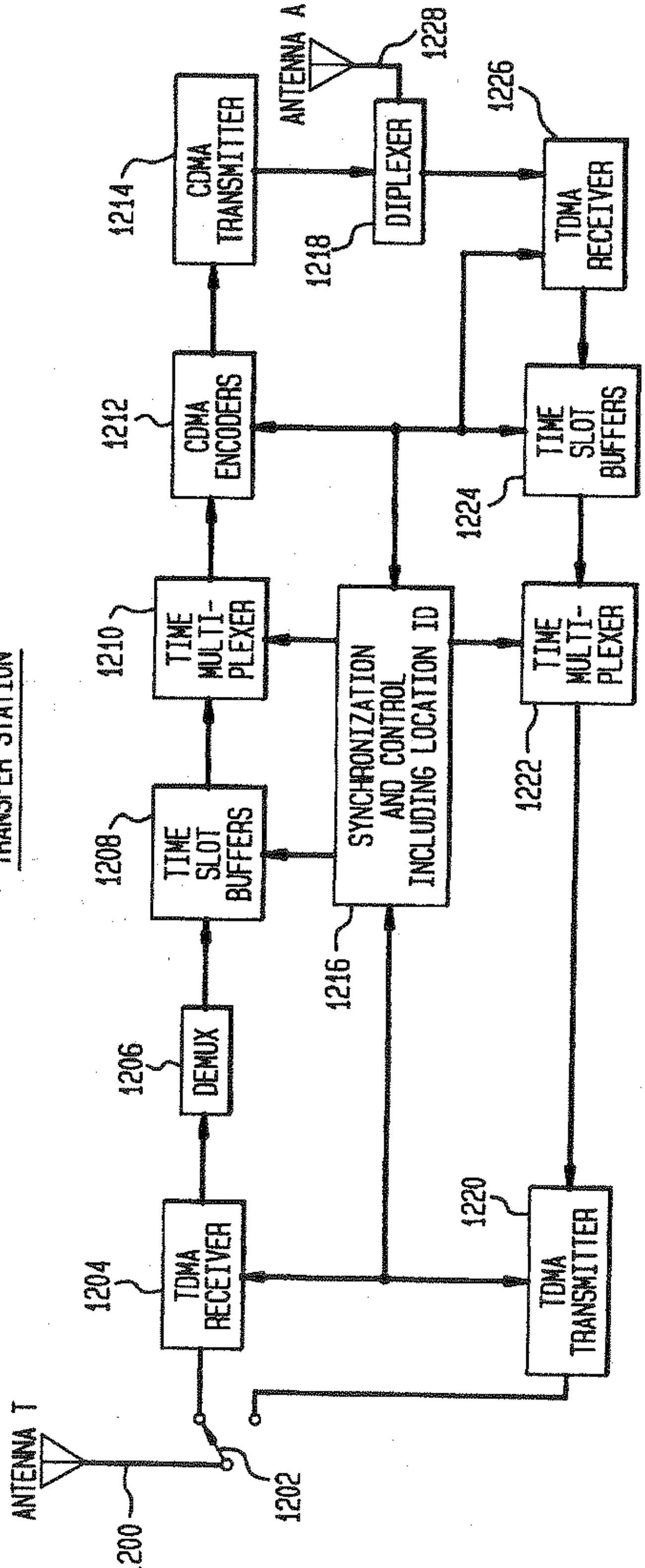


FIG. 12
TRANSFER STATION

FIG. 13

SUBSCRIBER STATION

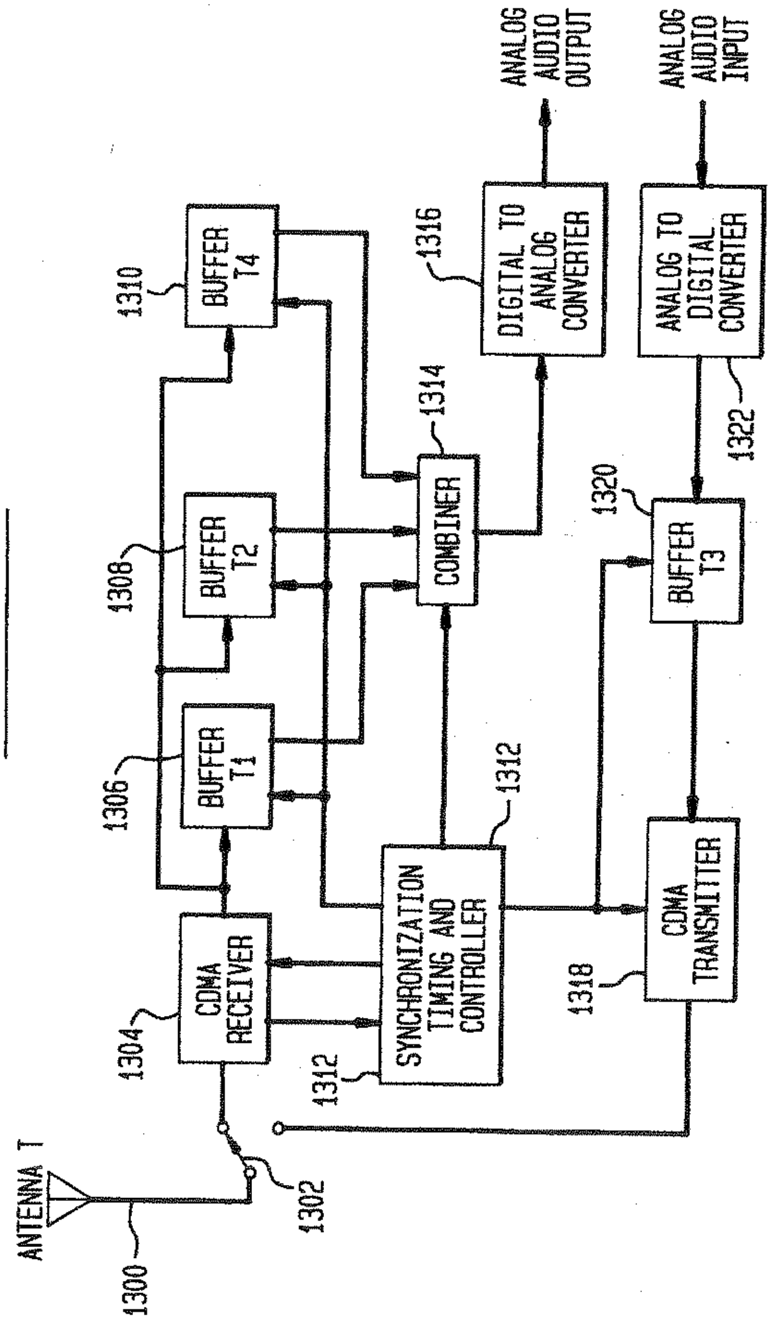


FIG. 14

CENTRALIZED AND INTEGRATED TRANSFER STATION

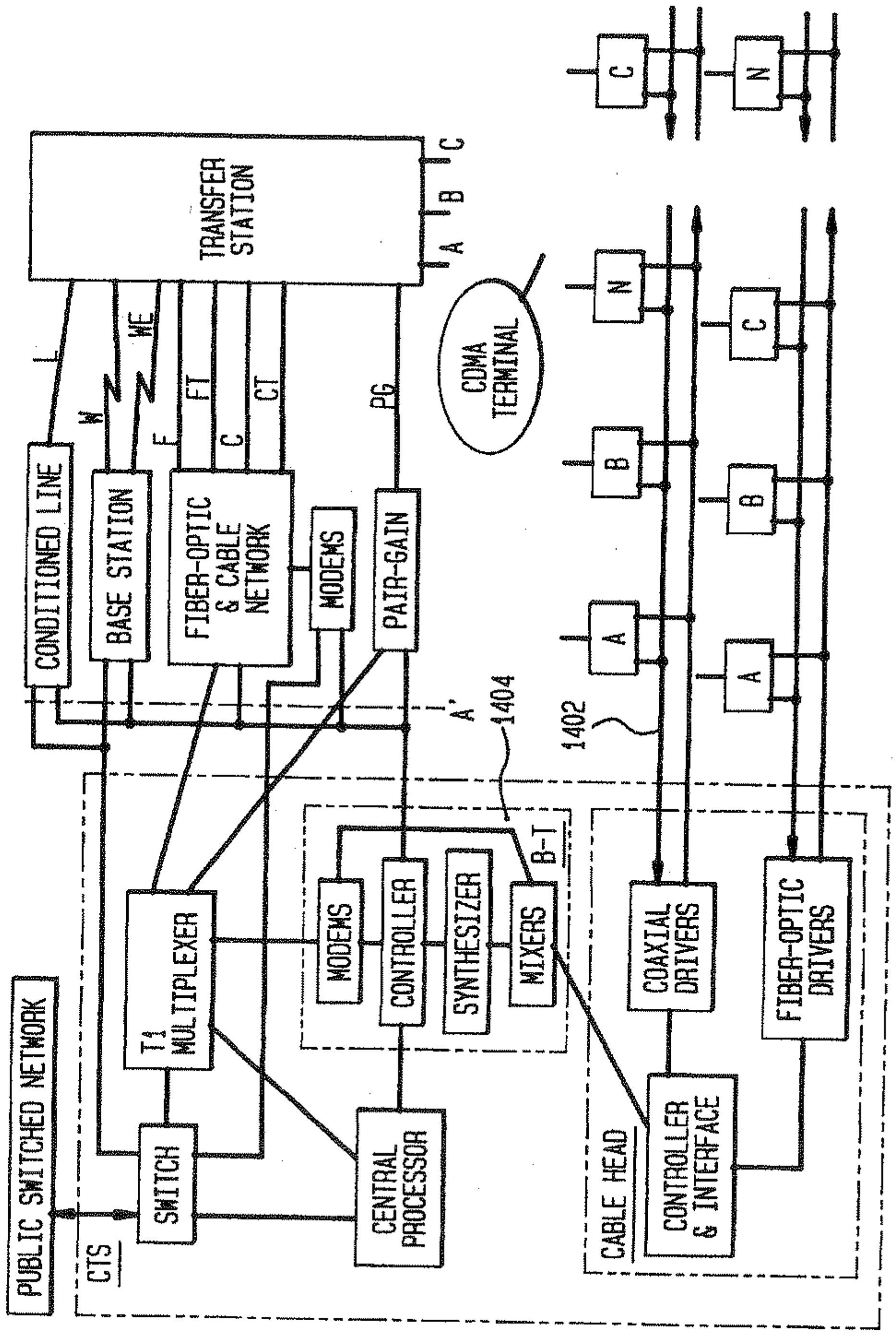


FIG. 15

TRANSFER STATION ANTENNA IMPLEMENTATION

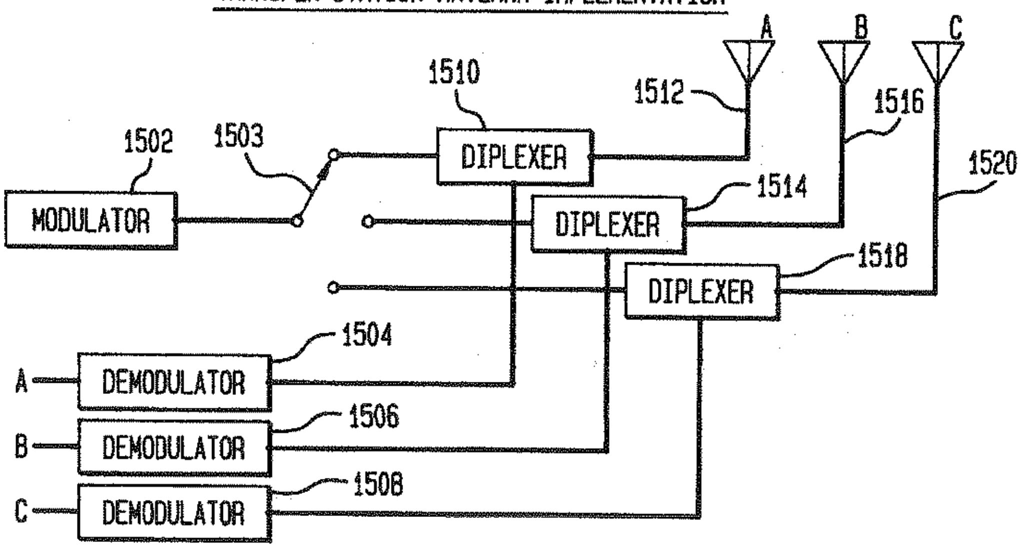


FIG. 16

DISTRIBUTED ANTENNA IMPLEMENTATION USING CABLE OR FIBER-OPTIC CABLE

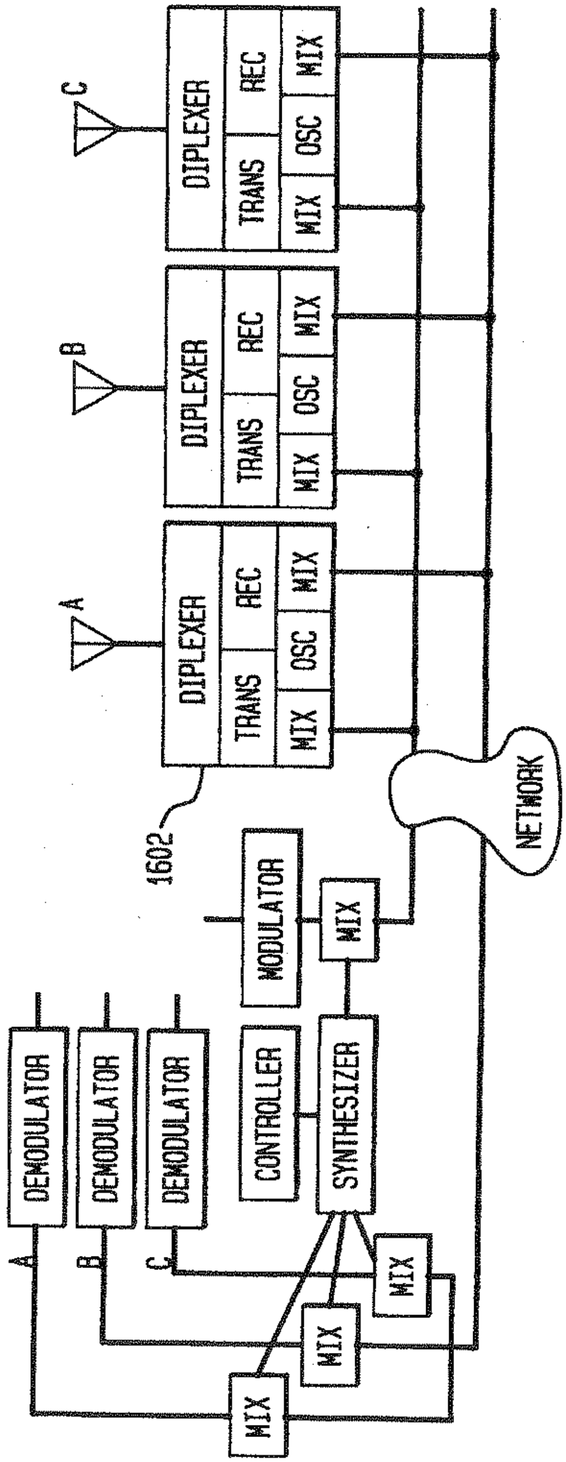


FIG. 17

SYNCH AND CONTROL CHANNEL STRUCTURE

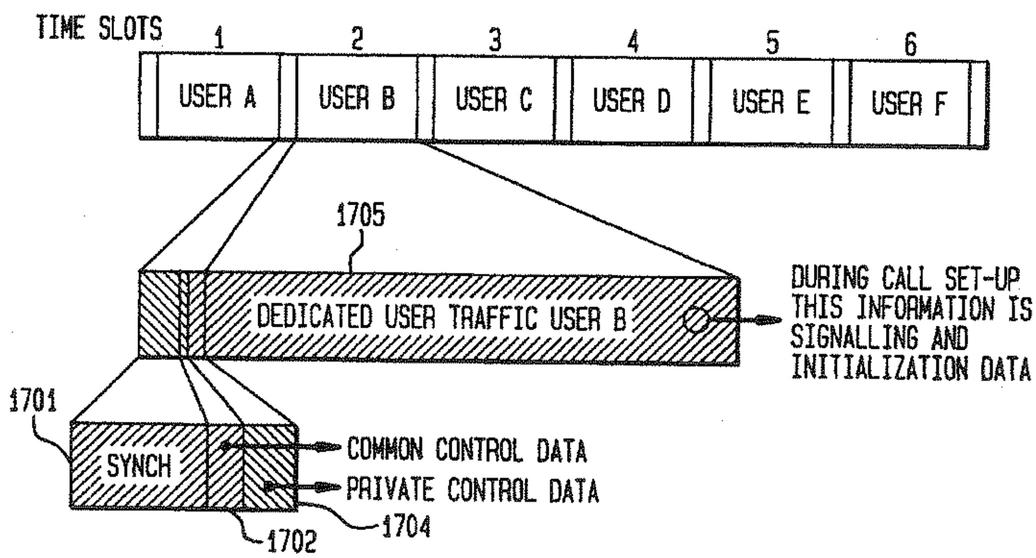


FIG. 18

TIME CALIBRATION FOR DISTRIBUTED ANTENNA IMPLEMENTATION

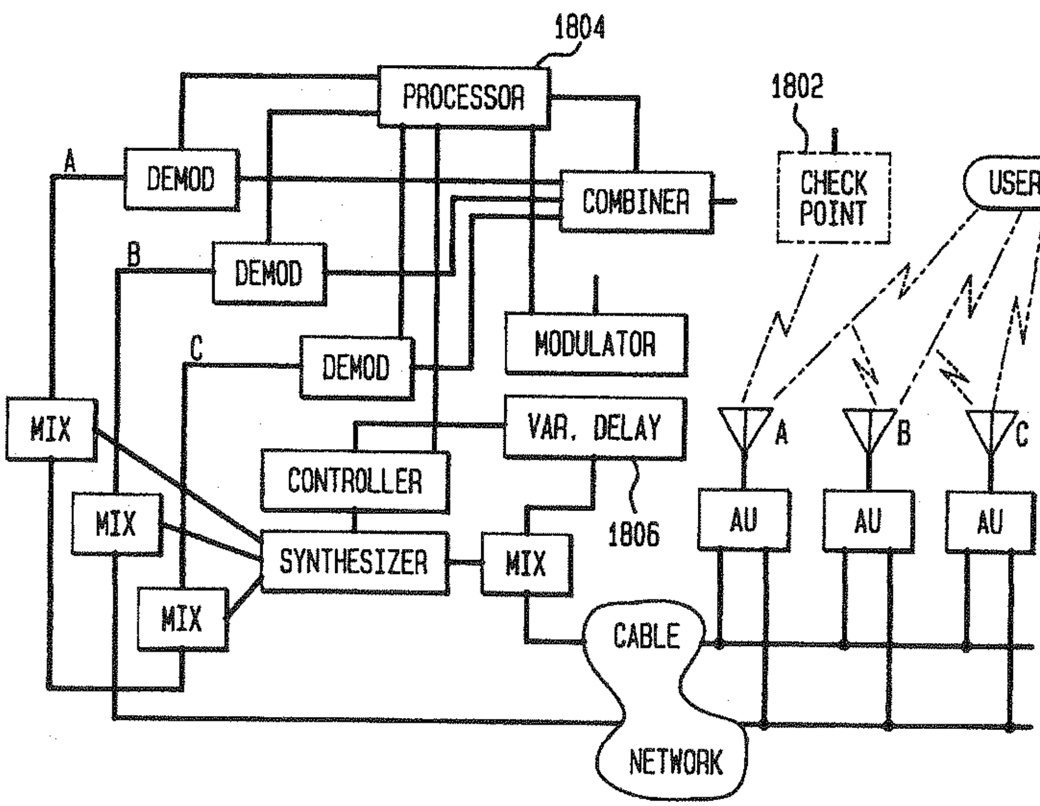


FIG. 19

LOCATION CENTER EXTERNAL TO COMMUNICAITON SYSTEM

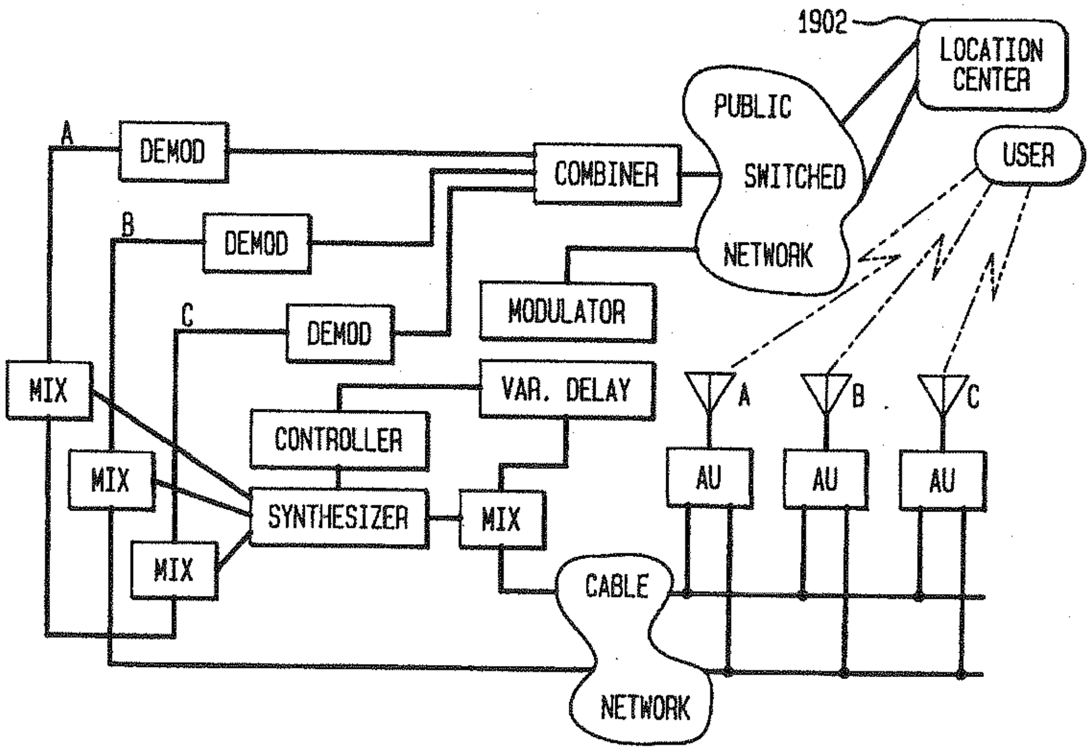


FIG. 20

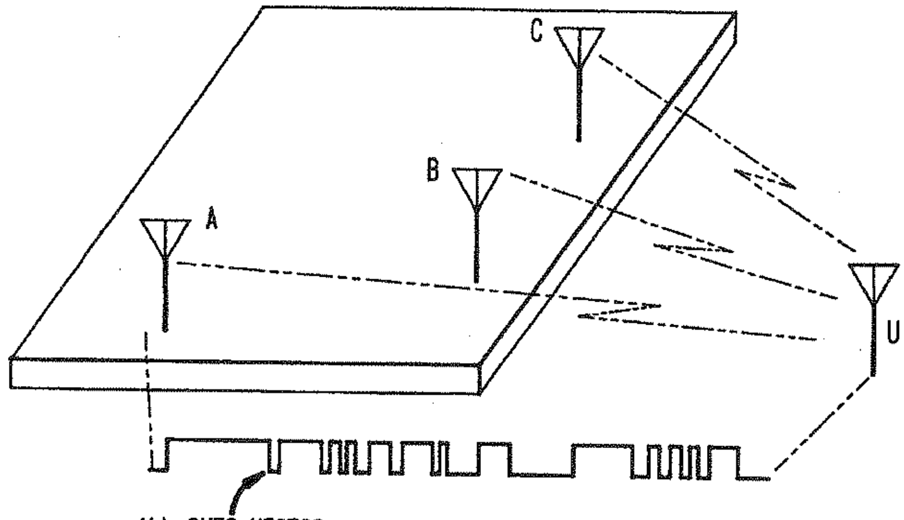

C
B
A
U
ALL ONES VECTOR
FIGURE 20

FIG. 21

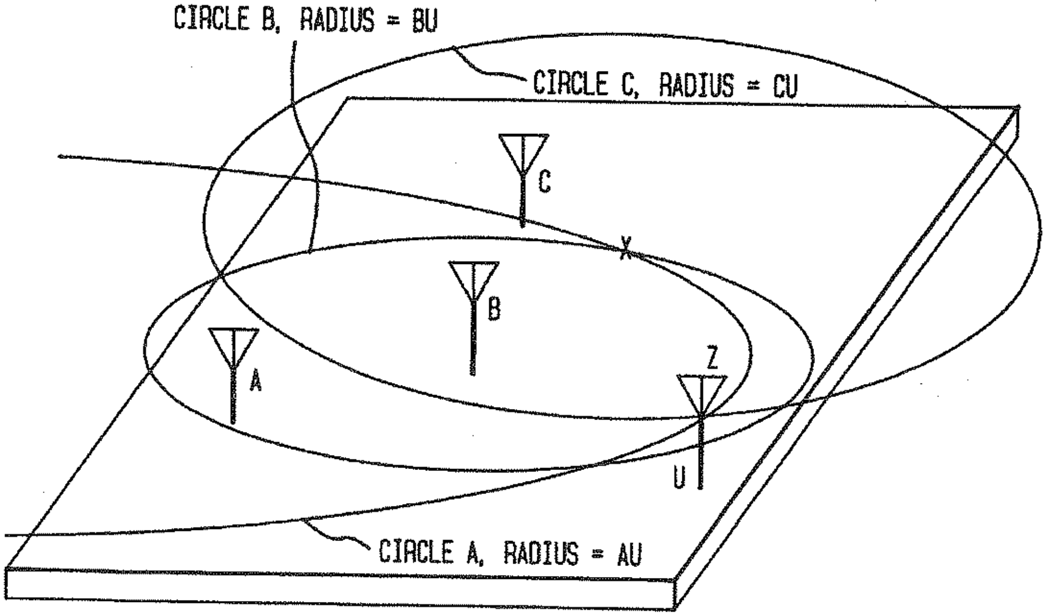

CIRCLE B, RADIUS = BU
CIRCLE C, RADIUS = CU
C
X
B
A
Z
U
CIRCLE A, RADIUS = AU

FIG. 22

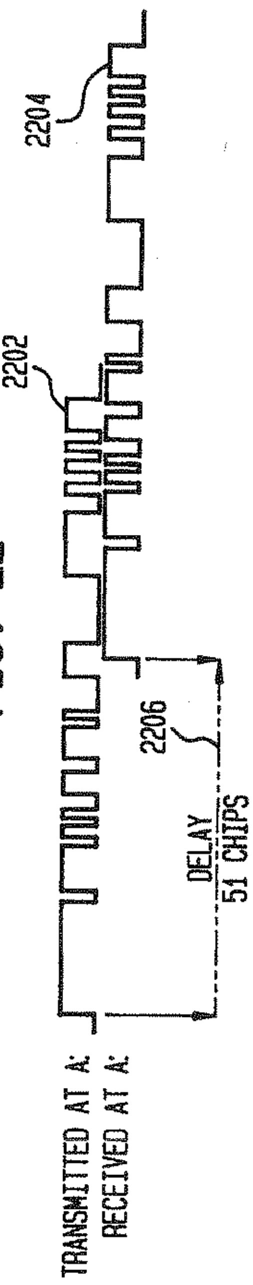
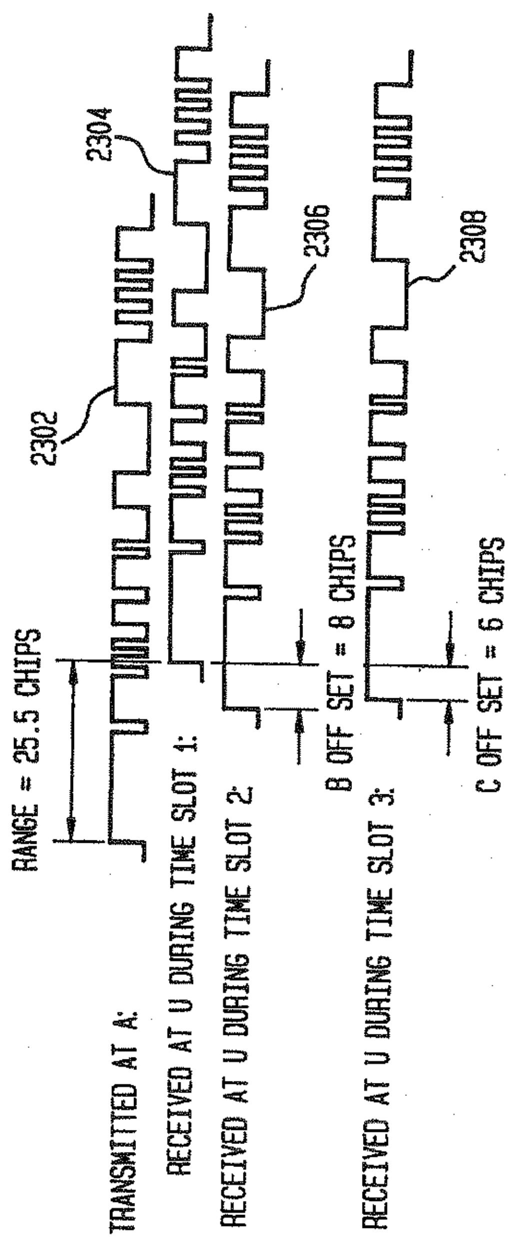

TRANSMITTED AT A:
RECEIVED AT A:
2202
2204
2206
DELAY
51 CHIPS

FIG. 23


RANGE = 25.5 CHIPS
TRANSMITTED AT A:
RECEIVED AT U DURING TIME SLOT 1:
RECEIVED AT U DURING TIME SLOT 2:
RECEIVED AT U DURING TIME SLOT 3:
B OFF SET = 8 CHIPS
C OFF SET = 6 CHIPS
2302
2304
2306
2308

WIRELESS TELEPHONE DISTRIBUTION SYSTEM WITH TIME AND SPACE DIVERSITY TRANSMISSION

CROSS REFERENCE TO RELATED APPLICATIONS

This is a continuation of Ser. No. 538,863 filed Oct. 4, 1995, which is a division of Ser. No. 301230, filed Sep. 6, 1994, now U.S. Pat. 5,614,914.

FIELD OF THE INVENTION

The present invention relates to two way wireless communication systems. In particular, the present invention relates to wireless telephone systems with space diversity antennas and time diversity signal transmission for reducing signal fading and measuring subscriber location.

BACKGROUND OF THE INVENTION

Wireless radio communication is subject to the adverse effects of signal fading, in which the signal level at the receiver temporarily loses strength for a variety of reasons, such as from variable multipath reflections causing signal cancellation, time varying transmission loss due to atmospheric conditions, and mobile receiver movement introducing obstructions into the signal path, and the like. Signal fading causes poor reception, inconvenience, or in extreme cases, a loss of call connection.

It is known to use various forms of signal diversity to reduce fading. For example, as indicated in U.S. Pat. No. 5,280,472, signal diversity mitigates the deleterious effects of fading. There are three major types of diversity: time diversity, frequency diversity and space diversity.

Time diversity is obtained by the use of repetition, interleaving or error correction coding, which is a form of repetition. Error detection techniques in combination with automatic retransmission, provide a form of time diversity.

In frequency diversity, signal energy is spread over a wide bandwidth to combat fading. Frequency modulation (FM) is a form of frequency diversity. Another form of frequency diversity is code division multiple access (CDMA) also know as spread spectrum. Due to its inherent nature as a wideband signal, CDMA is less susceptible to fading as compared to a narrow band modulation signal. Since fading generally occurs in only a portion of the radio spectrum at any one given time, a spread spectrum signal is inherently resistant to the adverse effects of fading.

Space diversity is provided by transmitting or receiving the same signal on more than one geographically separated antennas. Space diversity provides alternate signal paths to guard against any one path being subject to fading at any one time. Space diversity also creates some time diversity since the receiver receives the same signal separated by small propagation delays. The difference in propagation delay requires that the receiver be able to discriminate between the arriving signals. One solution is to use multiple receivers, one for each arriving signal. For instance, it is known from U.S. Pat. No. 5,280,472 to deliberately introduce relatively small delays compared to an information symbol, into a space diversity multiple antenna CDMA system in order to create artificial multipath time diversity signals greater than one chip delay up to a few chips. CDMA systems are capable of discriminating between identical plural signals arriving at the receiver with different propagation delays greater than one chip delay. Such receivers are known as Rake receivers. However, prior art systems require multiple CDMA

receivers, one CDMA receiver for each separate received CDMA signal. It is desirable to provide a system for receiving time diversity CDMA signals which does not require multiple CDMA receivers.

Measuring or determining the location of mobile units is well known. In some systems, fixed antennas measure the mobile location. In other systems, the mobile unit determines its location from multiple received signals. If the system is two way, the communication link permits both the mobile subscriber and the fixed system to exchange location data. Various known systems use satellites or multiple antennas to provide information on the location of a mobile subscriber. For example, multiple directional receiving antennas can be used to triangulate the position of a mobile transmitter. In such systems, the stationary receivers determine the mobile subscriber location; in other systems, the mobile subscriber determines its location from the received signals. For example, the Global Position System (GPS) is a multiple satellite system providing signals which permit a mobile subscriber station to determine its position in latitude and longitude. However, both satellite systems and the GPS receivers for receiving satellite signals tend to be expensive.

The combination of a GPS receiver and a cellular telephone is shown in U.S. Pat. No. 5,223,844. Such combination provides useful services, as for example a security alarm service to deter car theft, in which tripping the alarm also alerts the security service to the location of the car. Generally, it is desirable to provide a system which combines telephone or data service with location measurement at a reasonable cost.

It is desirable to provide a system of time diversity signals using time division multiple access (TDMA) in various combinations with CDMA and space diversity antennas, to provide a variety of systems which resist fading, reduce receiver cost, and provide location measurement for mobile subscribers.

SUMMARY OF THE INVENTION

The present invention is embodied in a wireless communication system in which time diversity and space diversity is used to reduce fading and simplify receiver design. The present invention is further embodied in a wireless communication system in which time division signals are code division (spread spectrum) multiplexed onto space diverse antennas to provide a wireless communication system with the ability to determine subscriber location using the same communication signals which are used for the primary wireless communication.

Specifically, a data packet which for example may carry telephone voice traffic, is transmitted at three different times from three different antennas. The receiver thus receives the same data packet at three different times from three different antennas. The receiver uses the best data packet or combination of the data packets to reduce the effects of fading.

In addition, the receiver uses the absolute and extrapolated relative time of arrival of the three data packets to determine its location from the three transmitting antennas. First, absolute range to one antenna is determined by the time required for a round trip message. Then, the relative time of arrival of data packets, referenced to a universal time, from the two other antennas indicates the relative distances as compared to the first antenna. Since all three transmitting antennas are at known fixed locations, the receiver computes its own location as the intersection of three constant distance curves (in the two dimensional case, circles, or in the three dimensional case, the intersection of

three spheres). In the alternative, the mobile subscriber station provides raw delay measurement data back to a fixed station, or location service center, which computes the mobile subscriber location.

More particularly, the present invention is embodied in a system using CDMA to modulate a TDMA signal which is transmitted from three space diversity antennas. In a first embodiment, the TDMA signals are used to transmit multiple repetitions of the same data packet from a transfer station with three space diversity antennas. In a second embodiment, the TDMA signals are used to transmit multiple repetitions of the same data packet from three transfer stations each transfer station including one of the three space diversity antennas. The data packets could either be identical, or could carry substantially the same information, but modulated with different spreading codes or different segments of the same spreading code.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 is a system diagram of a wireless telephone distribution system including a first embodiment of a transfer station in accordance with the present invention.

FIG. 2 is a block diagram of a first embodiment of a wireless telephone distribution system in accordance with the present invention.

FIG. 3 is a system diagram of a first embodiment of a wireless telephone distribution system in accordance with the present invention.

FIG. 4 is a system diagram of a wireless telephone distribution system including a second embodiment of a transfer station in accordance with the present invention.

FIG. 5 is a system diagram of a second embodiment of a wireless telephone distribution system in accordance with the present invention.

FIG. 6 is a block diagram of a second embodiment of a wireless telephone distribution system in accordance with the present invention.

FIG. 7 is timing diagram of a time division multiplex signal which modulates a code division multiplex signal in accordance with the present invention.

FIGS. 8 and 9 are a block diagram of a first embodiment of a transfer station in accordance with the present invention.

FIG. 10A is a time slot assignment diagram of a wireless telephone distribution system in accordance with the present invention illustrating the time division multiplexing and code division multiplexing for 6 simultaneous calls.

FIG. 10B is a time slot assignment diagram of a wireless telephone distribution system in accordance with the present invention illustrating the time division multiplexing and code division multiplexing for 12 simultaneous calls.

FIGS. 11A and 11B are a time slot assignment diagram of a wireless telephone distribution system in accordance with the present invention illustrating the time division multiplexing and code division multiplexing for 24 simultaneous calls.

FIG. 12 is a block diagram of a second embodiment of a transfer station in accordance with the present invention.

FIG. 13 is a block diagram of a subscriber station in accordance with the present invention.

FIG. 14 is a block diagram of a centralized and integrated transfer station in accordance with the present invention.

FIG. 15 is a block diagram of a transfer station antenna implementation.

FIG. 16 is a block diagram of a distributed antenna implementation of the present invention using coaxial cable or fiber optic cable.

FIG. 17 is timing diagram of a time division multiplex signal which is modulates a code division multiplex signal in accordance with the present invention.

FIG. 18 is system diagram illustrating a distributed antenna implementation of the present invention.

FIG. 19 is a block diagram illustrating a system in accordance with the present wherein the location center is external to the communication system.

FIG. 20 is an illustration of a system in accordance with the present invention for determining location of a mobile subscriber station.

FIG. 21 is a system in accordance with the present invention illustrating a method for determining location of a mobile subscriber station.

FIG. 22 is a timing diagram illustrating a method for determining the distance from a subscriber station and to a transmitting transfer station.

FIG. 23 is a timing diagram illustrating a method for determining the relative distances from a subscriber station to two transmitting transfer stations.

DETAILED DESCRIPTION

SYSTEM DESCRIPTION—FIRST EMBODIMENT FIGS. 1, 2, 3, 8, 9

In a first embodiment of the invention shown in FIG. 1, a mobile user having an antenna 10 is coupled to a CDMA transfer station 14. The CDMA transfer station 14 further includes an antenna T, 16, antenna A, 11, antenna B, 12, and antenna C, 13. Antennas A, B and C can be mounted either on separate structures as is shown, or on a single mast. The only physical requirement is that the space between antennas should be sufficient for uncorrelated space diversity. While a quarter wavelength spacing may be sufficient, at least ten wavelengths is preferable. At 1 GHz, 10 wavelengths is about 30 feet, while at 5 GHz, 10 wavelengths is about 6 feet.

The mobile subscriber antenna 10 (also referred herein as the user terminal antenna, or the subscriber station antenna, or simply antenna U) is coupled by a bidirectional radio link to antennas A, B and C. The CDMA transfer station 14 is further coupled by a bidirectional radio link through antenna T through appropriate switching to the public switch telephone network.

In operation, forward channel telephone voice traffic received in data packets on antenna T is transmitted on antenna A during time slot 1, repeated on antenna B during time slot 2, and further repeated on antenna C during time slot 3. All three repeated data packets are sequentially received on antenna 10. In the reverse direction, data packets representing telephone voice traffic transmitted from antenna 10 are substantially simultaneously received on antennas A, B and C. The CDMA transfer station 14 further retransmits data packets received in the reverse direction through antenna T back to the telephone network.

FIG. 2 is an overview diagram of a system in accordance with the present invention that includes the different interconnections between the supporting network, i.e., between the public switched network 20 and switching center and central processor 22, and the CDMA transfer stations 26, 28, 30, 32, 34, 36 and 38.

The user at CDMA subscriber station 42 is linked by antenna 10 to the CDMA transfer station 38 through antennas A, B and C. Antenna T, 39 on CDMA transfer station 38 carries wireless TDMA telephone voice traffic to antenna 25

on base station 24. Each of the other CDMA transfer stations are coupled to the switching center 22 by a variety of interconnection means. Connection means W between TDMA base station 24 and CDMA transfer station 36 is a wireless means, having a TDMA channel structure with six TDMA slots. The wireless TDMA distribution interconnection WE may be a commercially available wireless local loop system such as the Ultraphone® digital radio telephone system provided by Interdigital Communications Corporation. The TDMA time slot structure is carried through the transfer station to become the time slot structure for the slotted CDMA signal on the output. Connection means WE is the same as connection W except there are four W modules operating in parallel to provide a basic connectivity for 24 voice channels. Connection means F uses a fiberoptic cable that connects between the switching center 22 to the CDMA transfer station 32 without going through a wireless base station. Since connection means F (fiberoptic cable) incorporates a modem with a TDM/TDMA channel structure similar to W and WE it readily interfaces with the transfer station. Connection FT (fiberoptic cable carrying standard T1 multiplex) between switching center 22 and CDMA transfer station 30 is a fiberoptic cable that uses a standard T1 multiplexer as the channel combining means. Therefore, the transfer station that handles the WE connection means could readily be adapted to operate with the FT connection means. Connections C (coaxial cable) to CDMA transfer station 26, and CT to CDMA transfer station 28, (coaxial cable carrying T1 standard multiplex) are cable means that function like F and FT respectively. Connection means L to CDMA transfer station 36 is a conditioned line that carries up to a 100 kb/s data stream that has the same structure as the wireless TDMA, connection means W. Connection means LE (not shown) utilizes 4 conditioned lines to function in the same way as connection means WE. Connection means PG to CDMA transfer station 34 is a pair gain capability that is interfaced into a transfer station.

Using a combination of over the air and fiberoptic/cable media, to connect to the transfer stations, and a common output air interface, between the transfer stations and the CDMA user terminals, results in a flexible rapid response and economical solution. In addition, normal telephone lines conditioned to handle 64 kb/s to 100 kb/s could also be used to replace the TDMA wireless input to the transfer station. It also is very cost effective to connect the input side of the transfer station to the output of a pair gain module. Since the air interface remains the same for all these interconnection means, this extended concept becomes a very cost effective solution and transition vehicle.

In the system diagram of FIG. 3, telephone voice traffic through the public switched network 20, is coupled to a TDMA base station 24 having antenna 25 for the transmission and reception of TDMA signals. A plurality of CDMA transfer stations 44, 46, 48, 50 and 52 provide wireless telephone service for a plurality of subscribers 45 and 47. Each CDMA transfer station includes an antenna T for receiving and transmitting TDMA signals, as well as separate antenna A, antenna B and antenna C for communicating with mobile subscribers 45 and 47. By way of example, the TDMA base station 24 may have a range of 35 mile radius covering numerous CDMA transfer stations. Each CDMA transfer station may typically have a range of five miles and be spaced three miles apart to provide cellular coverage for the entire area. Subscriber 45 will be served by CDMA transfer station 46, while subscriber 47 will be served by CDMA transfer station 50. As subscribers move about the system, a different CDMA transfer station will be assigned to serve that subscriber.

An alternate embodiment capitalizes on the rich connectivity described above to more widely distribute the three antennas that are used to give transmission space diversity. The wider distribution allows compensation for not only multipath fading, but fading due to blockage. For instance if the CDMA user (antenna 10 in FIG. 1) goes behind a building or hill the signal from all three space diversity antennas, on a single transfer station, would fade.

However, if the energy in each time slot was transmitted from different transfer stations as in FIG. 4, there is a high probability the user terminal would not be blocked from all three transfer stations at the same time. Therefore, it is possible to randomize the effects of fading due to blockage and be more similar to multipath fading. Randomization is accomplished by having the central controller assign the different time slots on an individual basis during the call setup process. When implemented using a W or WE connection means, there is little impact on the capacity between the base stations and the transfer stations, but it would increase the number of TDMA receivers. However, there is also a diversity improvement on the base station to transfer station link. Generally speaking, the impact on the other hard wired connection means is even less. A major advantage of using multiple transfer stations as transmission diversity sources is that it allows the user CDMA receiver to evaluate the quality of the signal from each transfer station and request a handoff for individual time slots as better links are found, providing a highly reliable and smooth transition as a user passes through an area.

SYSTEM DESCRIPTION—SECOND EMBODIMENT FIGS. 4, 5, 6, 12

FIG. 4 illustrates a wireless telephone distribution system with enhanced space diversity. As before, a mobile user antenna 10 is coupled to antenna A during time slot 1, antenna B during time slot 2 and antenna C during time slot 3. However, each of antennas A, B and C are mounted on separate respective CDMA transfer stations 54, 56 and 58. In particular, an antenna A, 60 is provided on CDMA transfer station 54, antenna B, 68 is provided CDMA transfer station 56, and antenna C, 64 is provided on CDMA transfer station 58. Each of the respective transfer stations 54, 56 and 58 are coupled through respective antennas 62, 70 and 66 to the TDMA wireless digital telephone system. The signals received from antennas A, B and C by the subscriber station antenna 10 are similar to that received in the configuration of FIG. 4. However, due to the separation of antennas A, B and C, at separate CDMA transfer stations 54, 58, 58, signal diversity both transmitting and receiving, is vastly improved.

The system configuration of FIG. 6 is similar to that of FIG. 2 with the exception that each CDMA transfer station has either an antenna B, or antenna B or an antenna C. For example, CDMA transfer station A, 108, has a separate antenna A, 109 The CDMA transfer station 106 has an antenna B, 107. Similarly, CDMA transfer station 104 has an antenna C, 105. Thus, the antenna 10 of CDMA subscriber station 112 receives signals from each of CDMA transfer stations 108, 106 and 104. The received signals are time division multiplexed in the sense that only one of antenna A, B or C is transmitting to antenna 10 at any one time. During transmission, however, antennas A, B and C provide multiple code division multiplexed signals to other users.

In this embodiment, each transfer station has only one type of antenna: either antenna A, antenna B or antenna C. A system arrangement covering a service area is illustrated

in FIG. 5. As before, the public switch network 72 is coupled to a TDMA base station 74 having a transmitting antenna 75 covering an area of approximately a 35 mile radius. Throughout the service area, CDMA transfer stations are spaced apart in one direction 84, and in another direction 86 are positioned to cover the service area. For illustration, a regular placement is shown. In practice, the CDMA transfer stations are placed so as to provide coverage whereby a plurality of subscribers 88, 90 are always within range of an A, B and C antenna. For example, CDMA transfer stations 76 and 82 are antenna A type, while CDMA transfer station 80 is an antenna C type and CDMA transfer station 78 is an antenna B type. Thus, subscriber 88 receives signals from CDMA transfer stations 76, 78 and 80, while subscriber 90 may receive signals from CDMA transfer station 82, 78 and 80.

A time slot structure for use in the present invention is shown in FIG. 7. Six time slots are used. Time slots 1 and 2 are used to receive, followed by time slot 3 wherein the subscriber station transmits, followed by time slot 4 also used for receiving. During time slot 5 and 6 the CDMA receiver scans the transmission from other transfer stations.

CALL ESTABLISHMENT

When a circuit is to be established or transferred, the base station assigns a base station and transfer station frequency pair, a slot and a PN sequence. It then transmits to the transfer station all of these assignments and identifies which subscriber is to use the circuit. During call setup, the transfer station passes on to the desired subscriber station, the slot and PN sequence assignments. For example, see FIG. 17 where the TDMA time slots 1 through 8 are associated with users A through F, respectively. In a given time slot, e.g., time slot 2, the message to user B contains synchronizing information 1701, common control data 1702 for system wide functions, private control data 1704 and dedicated user traffic 1705 for user B. The dedicated user traffic 1705 is used during call setup to transmit signalling information and initialization data.

FORWARD PATH

Signal compression and decompression, plus added bits for forward error correction (FEC) is performed at the base station. In the forward direction, (to the subscriber station), the base station transmits continuously but the information in each slot is directed to a particular subscriber station.

By way of example, the base station may transmit the information during slot 1 on frequency fa. The transfer station receives the information by demodulating the signal on frequency fa during slot 1, and regenerating the information only at the symbol or bit level. The transfer station does not perform any decoding (i.e., error correction, compression or decompression) The transfer station design is thus simplified by accepting the already coded signal from the TDMA base station. After regeneration at the symbol level, the received TDMA signal is combined with the assigned PN sequence and retransmitted from the transfer station as a CDMA signal on frequency fp without any intentional delay to antenna A. The transfer station further stores the information received from the base station in a memory buffer. At the end of the antenna A transmission, the information bits stored in memory buffer are modulated onto a continuation of the PN signal and broadcast through an appropriate transmitter to antenna B. Thus, the identical information signal using the same PN sequence, but incremented a fixed number of chips, is transmitted at antenna B.

The relative position, or phase of the PN sequence relative to the transmitted information is different. At the conclusion of the first repeat, information in the time slot buffer is read out a third time to provide a third repetition of the information, modulated by a continuation of the PN sequence, with still a different phase, through an appropriate transmitter to antenna C.

SUBSCRIBER STATION PROCESSING

The subscriber station, using the correct CDMA code, receives during each of the three slots containing information signal repetition, so that it receives three identical repeats of the data packet from three antennas located in different locations. The subscriber station then compares the three receptions and selects the one with the best quality which may be based on bit error rate, phase distortion, signal to noise ratio, etc. Thus, spacial transmit diversity is achieved. Only one antenna is needed at the subscriber station. The subscriber station demodulates and decodes the signal, performs error correction, decompression, etc. A maximum likelihood combiner may be used to combine the power from all three time slots. Ideally, the energy of received data packets is combined in a maximal manner before making a hard decision.

During the third time slot T3, the subscriber station transmits back to the transfer station using a similar PN sequence as it received. The PN sequence may be the one derived from reception (after regeneration) or it can be locally generated on the basis of the original code received during call setup. Since the subscriber station does not transmit during the same time period as it receives, no diplexer or notch filter is needed. A simple T/R (transmit/receive) switch is used to switch the antenna between transmit and receive. Only one receiver is necessary in the subscriber station to achieve three branch diversity. The three chains needed by a Rake receiver, are not needed in the present invention.

Furthermore, the benefits of triple time and space redundancy, with some frequency protection provided by the expanded spectrum, are not obtained by adversely affecting capacity. The three branch diversity typically achieves a reduction for deep fades of at least 10 dB (a factor of 10x). While the three transmitted repetitions of the same information signal increases the interference level by a factor of 3 (about 5 dB) , because the fades are 10 dB less, the transmitter power levels can be reduced by a factor of 10 (10 dB). Thus the overall amount of interference is reduced by a factor of 10/3 or 5 dB. Because the transfer station to subscriber link is operated in a self interference mode that means that about three times as many simultaneous subscriber circuits can be used than if diversity were not used.

RETURN PATH

In the reverse direction (subscriber station to transfer station), three receivers are connected respectively to the three antennas at the transfer station to provide conventional three branch spacial diversity. The same analysis regarding interference and the number of circuits available, applies to transmission in the reverse direction as well as in the forward direction, except that the information is transmitted only once and is received simultaneously on the three base station antennas.

In addition to increasing the number of subscribers per unit frequency, the present invention is cost effective. First the subscriber station needs only one receiver. Second, it does not need a diplexer. Third, the transfer station does not

need to decode or re-encode any signals. The number of subscribers per transmitter is the same, however, since spacial diversity is used in the reverse direction, the number of subscribers per receiver increased. Conversely, the noise of the subscriber station can be allowed to be higher if the full use of the increase in the number of subscribers is not fully utilized.

The signal received by the transfer station from the subscriber station is retransmitted (again with symbol or bit level regeneration but without decoding), from the transfer station back to the base station without intentional delay during the same slot. As long as the slot is within the same TDMA frame or at least with one frame's duration of the slot used from the base station to the transfer station, no additional delay is incurred by the use of the present system.

TRANSFER STATION—FIRST EMBODIMENT FIGS. 8, 9, 15

The CDMA transfer station has a TDMA input at antenna T. The output side of the transfer station at antennas A, B and C, uses a CDMA structure to reach a large number of subscribers in relatively densely populated areas. CDMA possesses several attributes that make it desirable for this application. The wideband signal is inherently robust in a multipath environment and it has the ability to overcome interference, intentional and otherwise. The possibility that selective fading will cause the entire spectrum to be suppressed decreases as the transmitted spectrum increases. A higher chip rate, or increased TW product, reduces the amount of fade margin that is required to achieve a specified level of performance.

Spread spectrum signals have inherent multipath protection to protect against fading. However, statistical models generally do not take into account the frequency of occurrence or the duration of the fades. The specific geometry at each location, and how the geometry is changing with regard to the receiver, determines the actual fading patterns. For small cells, with low antennas, the difference in path length for strong signals is very likely to be small. The result is flat fading. That is, the spectrum across ten or fifteen megahertz will fade at the same time. Therefore, it is not possible to use the inherent multipath protection characteristics of spread spectrum signals to protect against flat fading unless at least 25 or 30 MHz of spectrum is available. In addition, there is often no multipath of consequence that would have enough delay to gain an advantage from an additional Rake receiver. Even so the use of real or artificial multipaths, requires additional receiver/correlators in the CDMA user terminal. Therefore, to maintain reliable operation using CDMA only, at least 15 dB of margin is required to be added to the link power allocation, particularly to account for the situation where a mobile user stops in one of the nulls or a fixed user shifts location geometry slightly.

The present invention utilizes the other important characteristic of spread spectrum systems, the ability to overcome interference, as the technique to combat the difficult multipath situations. The capacity of a CDMA system is limited by the amount of interference that is received by the desired receiver. As long as the TW product is great enough to bring the desired signal up out of the interference it doesn't matter what the transmitted data rate actually is. Therefore, with the present invention the transmitted information rate is increased to allow the transmitted signal to be repeated three times from three different antennas, thus obtaining transmission triple diversity which allows the transmitted power margin to be reduced by at least 10 dB for a high performance link. Therefore, even though additional interference is introduced into the links, the CDMA processing gain readily overcomes the adverse impact. That is, the gain from the triple diversity far exceeds, in a high quality system, the loss due to added interference.

A block diagram of transfer station in accordance with the first embodiment of this invention is shown in FIG. 8 for the forward channel. The TDMA antenna T, 916, is coupled through a transfer receive switch 918, to a TDMA receiver 800. The output of the TDMA receiver 800 is coupled to a demultiplexer 802, the output of which is stored in time slot buffers 806. A time multiplexer 808 accesses the contents of the time slot buffers 806 and provides data packets output to plural CDMA encoders 810 intended for antenna A transmission. The output of time multiplexer 808 also provides data packets output to plural CDMA encoders 812 intended for antenna C transmission. Similarly, the time multiplexer 808 provides data packets output to plural CDMA encoders 814 intended for antenna B transmission. Each of the plurality of CDMA encoders 810, 812 and 814 are provided to respective CDMA transmitters 816, 824 and 826. Each of CDMA transmitters is coupled to a respective antenna 822, 824 and 826 to provide respective antenna A, antenna B and antenna C transmissions.

The coordination of the timing and control of the TDMA receiver 800, as well as the time slot buffers 806, the time multiplexer 808 and each of the plurality of CDMA encoders, is controlled by a synchronization and control apparatus 804. The synchronization and control apparatus 804 also provides a location identification (ID) representing the particular transfer station to the plurality of CDMA encoders 810, 812 and 814 for inclusion on the transmitted signals at antennas A, B and C.

The transfer station of FIG. 8 also includes a CDMA receiver and TDMA transmitter 900, which is shown in further detail in the block diagram of FIG. 9. The TDMA transmitter is coupled to antenna 916 through transmit receive switch 918, while the CDMA receivers are coupled through respective diplexers to antenna A, antenna B and antenna C, as shown in further detail in FIG. 15.

FIG. 9 is a block diagram of a transfer station illustrating the structure of handling signals in the reverse channel. Antennas A, B and C, respectively shown as 822, 824 and 826 are coupled to respective CDMA receiver A, 902, CDMA receiver B, 904, and CDMA receiver C, 906. The output of the respective CDMA receivers A, B and C is fed to maximum likelihood combiner 908, the output of which is provided to memory buffers and time slot multiplexer 910. The memory buffers in time slot multiplexer 910 provide data packets to a TDMA transmitter 914 which is coupled through transmit receive switch 918 to antenna 916. The TDMA receiver and CDMA transmitter 828 corresponding to the block diagram of FIG. 8 is coupled to the other terminal of transmit receive switch 918.

FIG. 15 illustrates the antenna configuration of a transfer station permitting antenna A, antenna B and antenna C to be shared between TDMA and CDMA transmit and receive signals. Modulator 1502 is coupled through a time multiplexer 1503 to diplexers 1510, 1514, and 1518, respectively coupled to antenna A, 1512, antenna B. 1516 and antenna C, 1520. The other input of diplexers 1510, 1514 and 1518 is respectively coupled to the output of demodulator 1504, 1506 and 1508.

In the operation of FIG. 8, a TDMA signal received on antenna 916 is demultiplexed and placed in time slot buffers 806. A data packet intended for a given subscriber is selected

by time multiplexer **808** during time slot **1** to encode a CDMA signal by one of plural encoders **810** for transmission on antenna A. The same data packet is again selected by time multiplexer **808** to encode a CDMA signal by one of plural encoders **812** during time slot **2** for transmission on antenna B. Finally, the same data packet is subsequently selected by time multiplexer **808** to encode a CDMA signal by one of plural encoders **814** for transmission during time slot **4** on antenna C.

In the reverse direction, and in reference to FIG. **9**, the CDMA transmission from the subscriber station during time slot **3** is substantially simultaneously received on antennas **822, 824** and **826**. Each of the CDMA receivers **902, 904** and **906** receive the same data packet. A maximum likelihood combiner **904** combines the power from all three time slots before making a hard decision. Generally speaking, the signal which is strongest and error free will be selected. After selection, the data packet is held in a memory buffer and time slot multiplexer **910** waiting to be placed in its appropriate time slot for transmission by TDMA transmitter **914** on antenna **916**.

TRANSFER STATION—SECOND EMBODIMENT FIG. 12

A transfer station in accordance with the second embodiment of the present invention is shown in FIG. **12**. In essence, this transfer station is similar to the transfer station of FIGS. **8** and **9** except that only one CDMA antenna, A, B or C, is provided. In particular, in FIG. **12** antenna **1200** is coupled through a transmit receive switch **1202** to a TDMA receiver **1204**. The output of the TDMA receiver **1204** is demultiplexed in **1206** and placed in time slot buffers **1208**. A data packet placed in time slot buffer **1208** is time multiplexed by multiplexer **1210** to one of a plurality of CDMA encoders **1212**. The encoded CDMA signal is amplified in CDMA transmitter **1214**, coupled through diplexer **1218** to antenna A, **1228**.

Antenna A **1228** also operates to receive CDMA signals. Towards this end, a CDMA receiver **1226** is coupled to antenna A, **1228**, through diplexer **1218** to provide received data packets in combiner and time slot buffers **1224**. A time multiplexer **1222** takes the data packets in time slot buffers **1224** and composes a time multiplex signal to TDMA transmitter **1220** which is coupled through transmit receive switch **1202** to antenna **1200**. The operation of the transfer station is controlled by a synchronization and control apparatus **1216** which also includes unique location identification (ID) for this particular transfer station, and call setup control parameters.

In operation, the transfer station receives TDMA signals on antenna T, **1200** which are demodulated in TDMA receiver **1204**, and demultiplexed in demultiplexer **1206** for placement in time slot buffers **1208**. The data packets in time slot buffers **1208** are transmitted on antenna A during time slot **1**. Towards this end, time multiplexer **1210**, CDMA encoders **1212** and the CDMA transmitter **1214** retrieve the respective data packets from time slot buffers **1208** and encode the appropriate data packet in a CDMA encoded signal on antenna A. On the return path, CDMA receiver **1226** receives signals simultaneously on antennas A, B and C during all time slots. The received data packets are demodulated by respective PN codes, and placed in time slot combiner buffers **1224**, each time slot assigned to a different user. Thereafter, data packets are time multiplexed in multiplexer **1222** for transmission by the TDMA transmitter **1220** through the transmit receive switch **1202** on antenna **1200**.

The Transfer Station is the conversion point for mapping the TDM/TDMA signal into a CDMA signal. The CDMA signal, when designed properly has superior performance against multipath interference. The input side of the transfer station is part of a structured distribution network. It is basically a tandem relay point in the network, that is, the address to the final CDMA user also includes the address of the intermediary point (the transfer station) Since, in the general case, the final CDMA user may move and access the network through another transfer point it will be necessary to provide the ability to enter the transfer station address independent from the CDMA users address. For fixed subscribers such as the TDMA subscriber station **40** in FIG. **2**, this will not be an issue except for backup routing or for fade protection.

The preferred input network includes a number of base stations, transfer stations and TDMA user stations as shown in FIG. **2**. Any time slot on any frequency could be assigned to any TDMA user or transfer station. To reduce the cost of the transfer station it is proposed that once a CDMA user is connected through a specific transfer station any additional CDMA users, assigned to that transfer station, also be assigned to a time slot on the same frequency as the first user. By properly managing these assignments the number of TDMA radio elements can be reduced significantly. The base station **24** or the switching center and central processor **22** will manage the radio resource and assign the frequencies, time slots and the PN codes, thus assuring efficient use of the spectrum and the radios. The frequency, time slot and PN code are all assigned during the initial call setup process.

The local transmissions on the output side of the transfer station are CDMA, but each subscriber is assigned a specific time slot of a time division signal. Therefore, the individual information rate is increased by the number of time slots. However, the total data rate for all subscribers stays the same and the total transmitted power for all signals remains the same, it is just redistributed. Since the individual time slots are turned off unless there is activity the transmitted power is reduced by approximately 3 dB for voice traffic. Because the same information is transmitted three times the average transmitted power is increased by 5 dB. Therefore. the total transmitted power from each transfer station is increased by 5 dB, transmitting three times, but also reduced by 10 dB, diversity improvement, resulting in a 5 dB overall reduction in average power. Overall, the interference introduced into other cells is reduced by 5 dB.

The base station (**24** in FIG. **2**) or the switching center and central processor (**22** in FIG. **2**) will also manage the handoff process. There will have to be at least four time slots to obtain diversity on the CDMA side and still have a time slot for the CDMA receiver to scan other transfer stations. Four time slots only provide dual diversity. With five time slots it is possible to achieve the desired level of triple diversity. Of course, by adding additional receivers in the CDMA user's terminal it will be possible to scan in parallel for better synch signals. However, adding another receiver in all the CDMA users terminals would be an expensive solution. Therefore, with three time slots there is only dual diversity and no handoff. With four time slots there is triple diversity for fixed CDMA subscribers and dual diversity for mobile CDMA subscribers. With five time slots there is triple diversity for both fixed and mobile CDMA users. With six or more time slots there is the opportunity to add flexibility to the channel structure. FIG. 7 shows the CDMA user terminal slot structure for six time slots.

The triple antenna structure at the transfer station is used on the return link by simultaneously listening to a single

burst from each active subscriber, in his assigned time slot, on all three antennas, thus also achieving triple space diversity. The overall timing structure for the forward and reverse CDMA links, at the transfer station, are shown in FIG. 10A. For illustrative purposes six time slots have been shown, but as described previously any number of time slots, three or more, can be implemented, the upper reasonable bound being in the neighborhood of 32.

The order of transmission of the three active time slots can be distributed over the total number of time slots, and even more than three time slots could be used. With triple diversity the power transmitted from the CDMA user terminals can be reduced by at least 5 dB, probably more, but 5 dB is in keeping to match the performance of the forward link. In any case, the transmitted power is controlled and kept at the minimum level to maintain a high quality link. It is also possible, at higher frequencies, to achieve some antenna independence even on a relatively small radio or area. Therefore, a similar approach of the transmission space and time diversity, that is used on the forward link, may also be applied to the reverse link. Dual diversity should yield a significant improvement for most situations.

Each transfer station continuously transmits a spread spectrum channel for synchronization and control purposes. The synchronization and control channel identifies the particular transfer station and manages the user terminals as long as they are assigned to the transfer station. A large portion of the time the synchronization and control channel does not carry any user traffic. The synchronization and control channel can be a narrow band channel that can be easily acquired and tracked. The information bearing portion of the control signal has a preassigned time slot and includes system and signaling messages to all the users assigned to the particular area covered by that transfer station. The processing gain is sufficient to allow a transfer station to include several time slotted CDMA signals to be transmitted in parallel, thus allowing the antenna array to be shared. Also, only one synchronization and control channel is required for multiple slotted CDMA modules that are integrated at a single location.

SUBSCRIBER STATION FIG. 13

A block diagram of the subscriber station in accordance with the present invention is shown in FIG. 13. Antenna 1300 is coupled to CDMA receiver 1304 through transmit receive switch 1302. The output of CDMA receiver 1304 provides data packets to data buffers 1306, 1308 and 1310. A combiner 1314 selects and combines the data held in buffers 1306, 1308 and 1310 to provide an output to a digital to analog converter 1316, which also includes means for decompressing the compressed signal to provide an audio output. An analog audio input is provided to analog digital converter 1322, which also provides means for compressing the audio signal. The output of the analog to digital converter 1322 is a digital form of audio samples assembled as data packets in memory buffer 1320. A CDMA transmitter 1318 encodes the contents of memory buffer 1320 and provides a CDMA encoded signal through transmit receive switch 1302 to antenna 1300. The CDMA subscriber station is synchronized by a synchronization and timing controller 1312, which also measures signal delay for location measurement, described below.

In the forward direction, CDMA receiver 1304 receives three identical data packets placing one of the data packets during time slot T1 in buffer 1306, a second of the data packets during time slot T2 in memory buffer 1308, and a third data packet received during time slot T4 in memory buffer 1310. The combiner 1314 selects one or more of the contents of the memory buffers to be combined or selected as the best received data to be converted to an analog audio output of the output of digital to analog converter 1316. By using three time and space diversity data packets, the present system is less susceptible to fading and since the same receiver is used to demodulate all three samples, no complex signal strength balancing process is required.

In the reverse direction, the analog audio input to analog to digital converter 1322, which also includes a digital compression algorithm, provides a data packet to buffer 1320. During time slot T3 the CDMA transmitter 1318 encodes the contents of buffer 1320 for transmission as a CDMA signal on antenna 1300.

The simplification of the CDMA user terminal is a major consideration in the present system. The main simplification is the ability to time share the receiver, and particularly the correlator as it performs its different functions. The ability to transmit and receive at different times also simplifies the implementation of the small portable user terminal. The single receiver sequentially receives the three space diversity signals in the three different time slots and then moves to different codes to look for improved signals from other transfer stations. The same receiver is also used for the purpose of acquisition and tracking. Since the user terminal does not receive during the slot when it is transmitting there is no need for a diplexer and notch filter. Only a simple on/off switch is used. Since only one PN code is needed at a time, the PN code generation process is also greatly simplified. The baseband processing can be accomplished on a relatively low speed common processor.

In those time slots where the user terminal is not receiving or transmitting the receiver is free to look for the synchronization and control channels from other transfer stations. When the user terminal identifies a synchronization and control channel that is better than the one he is assigned, the user terminal sends a message to the network controller telling the controller that he has identified a potential candidate for handoff. The network controller uses this input, along with other information, to make the decision to handoff. The network controller sends the handoff message to the effected entities. The identity of the codes that are to be searched by the user terminal are provided by the network central controller through the transfer station where they are placed on the control channel.

TIME SLOT STRUCTURE FIGS. 10A, 10B, 11A, 11B, 17

The time slot assignment for multiplexing 6 simultaneous calls is shown in FIG. 10A. Time slots assignments for transmission 1002 and for reception 1004 are illustrated. The entry in each box contains the activity during the corresponding time slot. During time slot 1, antenna A transmits T1 to user 1, antenna B transmits T6 to user 6 and antenna C transmits T4 to user 4. At the same time, antennas A, B and C receive R5 from user 5. During the next time slot 2, antenna A transmits T2 to user 2, antenna B transmits T1 to user 1 and antenna C transmits T5 to user 5. At the same time antennas A, B and C receive R6 from user 6. Continuing across the diagram in FIG. 10A, during time slot 3, antenna A transmits T3 to user 3, antenna B transmits T2 to user 2 and antenna C transmits T6 to user 6. At the same time antennas A, B and C receive R1 from user 1.

Note that during time slot 3, none of the antennas A, B or C is transmitting to user 1. Instead, user 1 is transmitting and

the transfer station is receiving on all three antennas from user 1. However, during time slot 4, the third transmission to user 1 is transmitted. That is, during time slot 4, antenna A transmits T4 to user 4, antenna B transmits T3 to user 3 and antenna C transmits T1 to user 1. Time slots 5 and 6 are not directly used for data transfer to or from user 1. The time slot assignments shown in FIG. 10A, 10B, 11A and 11B are consistent with FIG. 7, wherein user 1 receives during time slots 1, 2 and 4, and transmits during time slot 3. The pattern can be seen in FIG. 10A slot assignments by looking for times when T1 is transmitted. Transmission of T1 appears in time slots 1, 2 and 4, on antennas A, B and C respectively. No transmission to T1 appears during T3, but reference to receiving time slots 1004 indicates that R1 is received from user 1 during time slot 3. Since in any given time slot, there are three transmissions and one reception simultaneously, at least 4 addressable CDMA PN spreading code sequences are required.

Thus, time division multiplexing is used in the sense that successive time slots carry data directed to different users. Code division multiplexing is used in the sense that during each time multiplexed time slot, multiple PN code sequences permit simultaneous communication with multiple users. The result is a time division multiplexed, code division multiplexed signal.

The time slot assignment for multiplexing 12 simultaneous calls is shown in FIG. 10B. Time slots assignments for transmission 1006 and for reception 1008 are illustrated. During time slot 1, antenna A transmits T1 to user 1 and T7 to user 7, antenna B transmits T6 to user 6, and T12 to user 12, and antenna C transmits T4 to user 4 and T10 to user 10. At the same time, antennas A, B and C receive R5 from user 5, and R11 from user 11.

The time slot assignment for multiplexing 24 simultaneous calls is shown in FIGS. 11A and 11B. FIG. 11A shows the transmission from the transfer station (forward direction), while FIG. 11B shows the transmission to the transfer station (reverse direction). Time slots assignments for transmission 1102, 1104, 1106 and for reception 1108 are illustrated. By way of example, during time slot 5, antenna A transmits T5, T11, T17 and T23 (i.e., T5 to user 5, T11 to user 11, etc.) Antenna B transmits T4, T10, T16 and T22. Antenna C transmits T2, T8, T14 and T20. At the same time, (during time slot 5), antennas A, B and C receive R3, R9, R15 and R21 (i.e., R3 from user 3, R9 from user 9, R15 from user 15 and R21 from user 21).

For FIG. 10A, one CDMA encoder per antenna is required to handle 6 simultaneous calls. In FIG. 10B, two CDMA encoders per antenna are required to handle 12 simultaneous calls. Similarly, in FIG. 11A, four CDMA encoders per antenna are required. Thus, for example, if 180 PN code sequences are available, then 180/6 or 30 CDMA encoders per antenna are required to handle 180 simultaneous calls. If, for these larger number of required accesses, the number of time slots is increased, the number of encoders will decrease proportionally.

ALTERNATE SYSTEM CONFIGURATIONS FIGS. 14, 16

A further enhancement extends the distance between the transfer station diversity antennas by using broadband cables that are a thousand feet or more. The transfer station sends the final radio frequency spread spectrum signal down the cable to the antenna. The antenna at the end of the cable contains a radio frequency amplifier. An implementation distributing signals by cable has the same improvement against blockage as described for the multiple transfer station transmission diversity approach.

However, instead of using a separate cable for each antenna, a preferred embodiment shares a single cable and uses frequency multiplexing to assign a different cable carrier frequency to each antenna. Thus, the desired signal is only transmitted from the antenna nearest to the user which reduces the interference. As a further enhancement, a cable distribution system integrates different elements into a local personal communications system network. The basic building block is the six time slotted CDMA module that serially drives three antennas to obtain triple transmission space and time diversity. For the sake of simplicity, the design of the transfer station handling the incoming TDMA signal also has a basic six time slot structure. The six time slot modularity can readily be deployed to accommodate multiples of 12, 18, 24, and 30 or 32. FIG. 14 shows the implementation for several different combinations. The preferred embodiment utilizes a wireless input, such as W or WE, as the input to the transfer station, however, a cable distribution system works equally well with hard wired signals as the input.

In a cable based personal communication system, the transfer stations are moved back to the central controller, which reduces the cost of the transfer station since it does not have to be ruggedized or remotely powered. It also reduces the number of spares required and the cost to maintain the units since they are all in one place and easy access. The transfer stations can also be dynamically reassigned as the traffic load changes during the day or week, thus significantly reducing the total number of required transfer stations. The bandwidth of the distribution network increases, but developments in cable and fiber optic distribution system have increasing bandwidth at falling cost to accommodate the increase in bandwidth at reasonable cost. The advantage of having several interconnection options to select means that the choice of interconnection becomes an economic choice determined by the cost factors associated with each installation. Each network is expected to include many or all of the interconnection options.

The system arrangement in which the transfer stations are moved back to the same location as the central controller, is depicted in the lower portion of FIG. 14. A general two-way cable or fiber optic wideband distribution system 1402 is used to link the centrally located transfer stations to the remotely located antennas. Considerable flexibility in configuring the wideband spectrum into signal formats is available for linking the centrally located transfer stations to each transfer station antenna. However, for simplicity it is preferable to retain the TDMA protocol with its time slotted CDMA triple space/time diversity air interface protocol, and frequency translate signal as a common air interface to each antenna.

Each antenna is assigned a separate center frequency on the wideband distribution cable 1402. Due to the TDMA and CDMA sharing ability, many users can be served on the same antenna using the same cable frequency. The transfer station antenna at location N, includes a transceiver which is tuned to the assigned cable frequency. The central controller transmits and receives data packets in the final TDMA/CDMA waveform representing telephone traffic on each assigned frequency of the wideband distribution cable 1402. Thus, as shown in FIG. 16, each remote location includes a remote transceiver (transmitter, receiver, local oscillator, diplexer and antenna) at site 1602. The remotely located unit is a relatively simple receiver, frequency translator and low power transmitter, for both the forward and reverse directions. A low power transmitter amplifier is suitable because

the cells are small and triple diversity (three antennas and three time slots) is being used to link the subscriber station to the system. The transmit side of the central controller provides individual information flows along with the associated signaling and control information at interface A' in FIG. 14, which is presented in assignable time slots in the form of packets.

The signaling information includes the called parties identification number(s), code, service profile and authentication code, etc. The control information includes routing information (i.e. which base station, transfer station, antenna designation), power levels, traffic on or off, handoff messages, etc. A large amount of this information is transmitted before the user information (telephone voice traffic) starts passing over the circuit, however, a significant amount of information is also passed during the time when telephone voice traffic is actually on the circuit. A separate control channel is required even after the connection to the user has been completed. The base station function translates this information into the protocol that is required to interface to the TDMA air interface and provides a TDMA radio spectrum at interface W. The transfer station converts the TDMA protocol to a time slotted CDMA triple space/time diversity air interface protocol and transmits this signal first on antenna A, then on antenna B and finally on antenna C (FIG. 14).

The centrally located combined base station and transfer station (B-T) module **1404** combines the base station and transfer station function and converts the signal appearing on A' to the time slotted CDMA triple diversity air interface. A B-T combined module may be achieved by direct combination of separate equipment, or the modules developed for the combined base station and transfer station use can be integrated. The CDMA signal branches at the output of the transfer station or at the output of the B-T module as shown in FIGS. **15** and **16**. In the case of the of the transfer stations which are connected to respective antennas by three different cables, the output is just switched at the appropriate time. When one cable is used to reach all the antennas the output of the transfer station is frequency hopped at the appropriate time by changing the synthesizer frequency to the assigned frequency of the antenna. The B-T module is similarly frequency agile.

It is important to note the user information is replicated in each of the three time slots, but the PN code continues to run and is different during each time slot. Therefore, the repetition is not the same as in the case of imitation multipath or emulated multipaths. The PN generator just keeps on running without storing or resetting the sequence. Running the PN code continuously is simpler to implement as compared to starting a PN sequence anew.

In the foregoing discussion, it is assumed the time slots follow one right after the other; this is not necessary, however, as long as the receiver has a priori knowledge of the hopping sequence. In the preferred embodiment, the B-T transmits on two contiguous time slots and then listens to the response signal from the user terminal. During the user transmission time slot the user terminal tells the B-T module to not send the third diversity time slot if the first two time slots have given adequate performance and location measurement is not needed. The use of only dual diversity reduces the interference to the other users, and frees up the user receiver to perform other functions.

An alternate approach is to utilize a ⅓ forward error correcting code that is spread over all three time slots. The use of such coding provides improved performance if the error statistics during each of the time slots are nearly the same. If one time slot becomes significantly worse, and it can be identified as being bad, it may be better to ignore the bad time slot and request an antenna handoff to replace that time slot if the poor performance continues. Since it is expected that the real diversity channel statistics will result in unequal time slot statistics, the preferred alternative is to not use a forward error correcting code over the three time slots. Even though error detecting and correcting codes are only included within each time slot, forward error correcting codes may be used over multiple time slots.

Each antenna, assuming there is data to transmit, transmits during each of the time slots. Since the data is transmitted three times there will be three CDMA signals transmitted in each time slot for each module assigned to that antenna. If there are 4 modules assigned to the antenna, 4 modules supports 24 users at any one time, there would be 12 CDMA signals emanating from the antenna in each time slot, (see FIG. **11A**, **11B**). If the duty factor is approximately 50% then only six CDMA signals will actually be transmitting and if 20 to 25% of the time the third time slot is not required only 4 to 5 CDMA signals would be transmitted at a time. The same antennas are used for the receive side, or reverse link, (user to transfer station).

As stated previously the user CDMA terminal transmits only during one time slot and the transfer station simultaneously receives that transmission on the same three antennas resulting in receiver triple space diversity. The three receive signals come into the transfer station, or B-T module, either on separate wires or at different frequencies, as shown in FIG. **15** and **16**, and are processed separately. These processed signals are summed together using maximum likelihood combiners. The S/I from each antenna path is measured and kept in memory over an interval of at least ten time slots. The record of signal statistics is used by the maximum likelihood combining process. Stored signal statistics are also useful in the decision process for executing handoff to other antennas.

The handoff process for the B-T cable network is based on the signal received from each of the antennas. The central processor receives information on the quality of the links in both directions. On the forward link it receives information from the user CDMA receiver operating on that link during an assigned time slot which is identified with a particular antenna. On the reverse link it receives information on the separate paths through different antennas. The information on the quality of paths through a particular antenna can be evaluated and compared to other current paths through different antennas and with other new paths that the user terminal is continuously searching. When a current path in a particular time slot continues to deteriorate and a better path is available the central controller assigns a new path (antenna) to the user terminal and notifies the user terminal it has done so.

The handoff process for the transfer station is similar except the handoff is generally between transfer stations rather than antennas. When handed off from transfer station to transfer station all three antennas associated with a particular transfer station are handed off with the transfer station. A few transfer stations may be implemented with widely separated antennas. In the case where there are transfer stations with widely separated antennas the handoff process described for B-T module could also be used.

Operational Description: A new subscriber turns on his CDMA user terminal and scans the synchronization codes until he acquires a synchronization code. The CDMA user

terminal then initiates a registration message. The transfer station receives this message and passes it to the central controller who acknowledges it with an acknowledgment message back to the user terminal. The central controller goes to the home register of the new terminal and obtains the user profile and places it in the file for active users. The new user is now registered and all calls will be forwarded to this new region of service.

There are 28 different synchronization codes and one synchronization code is assigned to each area. The 28 areas make up a region and the codes are repeated in the next region. The transfer stations within an area are given different shifts or starting points for their particular code. Therefore, each transfer station, or widely separated antenna, has an identifiable code. The central controller knows which antenna, or transfer station, that the new user registered through so the controller will route all information to the new user through that node. The central controller will also give the new user a set of codes, or different starting points on his current code, to search for the purpose of identifying diversity paths or handoff candidates. The new user continues to monitor the synchronization and control channel during half his time slots. The other half of his time slots he scans for better synchronization channels.

The user is paged on the control channel and given a CDMA and time slot assignment which he sets up so he will be ready for the beginning of the call. When the user requests service he is also given a CDMA code and time slot assignment for the duration of the call. The user terminal remains in this state until the end of the call, unless the signal in one or all the diversity paths becomes weak. Since the user receiver is continuously evaluating the incoming signals and scanning for better new paths, it will know if a path is going bad and will notify the central controller of this condition along with a list of better candidates. The central controller will order a handoff and the user terminal will go to the new CDMA code and time slot. None of this activity is detectable by the end user.

At the beginning of each time slot is a short unmodulated section, without user information, used for resynchronization and range adjustment, followed by a short control message section. These short bursts are sent whether there is user information to be sent or not. If no user information is to be sent the control message confirms this and the transmitter power is reduced by ten db. for the user information portion of the time slot. It should be noted four time slots are available on the forward channel for passing user information depending on what agreements have been established between the user and the central controller. These slots as described above can be turned off so that other users have access to additional capacity. The multiple time slots can be used for diversity improvement or sending increased data rates, multiple data channels or a graphics channel along with a voice channel. The possibility of extending several parties on a conference call is also possible.

LOCATION PROCESSING FIGS. 20, 21, 22, 23

FIG. 20 shows the radio links of FIG. 1 or FIG. 4, where the car and its antenna are represented by user antenna U. The radio links are time slotted as shown in FIG. 10A. The radio link AU is time slotted and is present during time slot 1. Radio link BU is also time slotted and is present during time slot 2. Radio link CU is also time slotted and is present during time slot 4. Radio link AU establishes the absolute range from U to antenna A. The range to antenna A forms a reference to measure the difference in path lengths between radio links AU and BU. Similarly, the path length of radio link AU is also used as a reference to measure the difference in path lengths between radio links AU and CU.

Since the time occurrence of the all ones vector (for synchronization) is the same at all three antennas, the ranges to all three antennas may be derived from the difference in respective arrival times of the all ones vector within each time slot. The location center, having the physical geographic coordinates of all three antennas, calculates the location of the users antenna U.

The geometry of location determination is shown in FIGS. 20, 21, 22 and 23. The first range measurement AU establishes the user as someplace on circle A in FIG. 21. The second range determination establishes the user as also being someplace on circle B. The only locations this can be true is where the circles intersect each other at points X and Z. Therefore, his location has been narrowed down to two possible points. The third range determination establishes the user someplace on circle C. Since the user is also on circle C, he must be at point Z. Obtaining additional ranges to other antennas confirms the first set of measurements and in many cases improves on the accuracy. If the terrain has significant variations in height the constant range circles become constant range spheres and the extra measurements remove any ambiguity that could be caused by adding the third dimension. The position location processing center converts these coordinates into user friendly instructions. Range measurements by the CDMA system are obtained as follows:

1. The pseudo noise code as it is stretched out between A and U to act as a yardstick. The time required to propagate between A and U allows many chips, the propagation time in microseconds times the chip rate in megachips, to represent the length of the link or be "stored" in the link during signal propagation. See FIG. 20.
2. There are two ways to increase the number of chips stored in the propagation path. One is to increase the path length and the other is to speed up the chip clock rate. Increasing the chip clock rate is analogous to marking a ruler in a smaller scale. Therefore, increasing the chip clock rate stores more chips in the path delay and makes it possible to make more accurate measurements.
3. The path length from antenna A to user terminal U and back to antenna A, can be measured by transmitting from A, then retransmitting the same PN code, with the arriving phase, from user terminal U, and comparing the repeated signal as it is received back at antenna A to the signal that was previously transmitted from antenna A. By delaying the original signal until it matches, chip by chip, the received signal, at A, and counting the number of chips that are slipped, the total delay is proportional to twice the distance between antenna A and antenna U.
4. The accuracy of the distance measurement is approximately ¼ of the number of feet represented by one chip. The ¼ chip is an implementation constraint determined by how precisely the correlation peak is detected and tracked. It is possible to reduce this error by autocorrelation techniques, but ¼ chip is a realistic resolution.
5. To determine the path length between antenna A and user terminal U, described in paragraph 3 above, FIG. 22 shows the signals 2202 transmitted and signals 2204 received at antenna A. At a chip clock rate of 10 megachips per second, there are approximately 100 feet represented by each chip. The delay of 51 chips between transmitted 2202 and received 2204 signals represents the time required for a radio wave to traverse a round trip between the subscriber station and the transfer station.

One half of the round trip delay, or 25.5 chips represents the distance to the antenna. Thus, the distance from antenna A to user terminal antenna U for the example in FIG. 22 is (51×100)/2=2550 feet. The distance measurement accuracy is plus or minus 25 feet (100 feet/4).

6. Thus, the distance AU is measured quite precisely. As described previously the receiver uses a single receiver for all time slots. While the subscriber receiver is listening to time slot one it is working in conjunction with the base station, to repeat the received waveform, same phase with no delay through the user terminal. The base station receiver, as described above, compares the received phase with the transmitted phase to determine absolute range. The base station then transmits the range value, thus measured, to the user terminal where it is stored for future retrieval and use. As noted above it is the waveform phase that is important, if the starting point, the all ones vector, is maintained through the user terminal, a new similar PN code may be substituted on the reverse link. A similar code could include that same code shifted by a defined offset.
7. The same forward and return measurement process described above, could be used to obtain the other two ranges (to antennas B and C) with the results also stored in memory at the user station. However, direct range measurement to all three antennas is not necessary. See FIG. 23. The same receiver retrieves information over all three paths. In so doing, the receiver adjusts for the difference in path length at the beginning of each time slot. Once the adjustment is accomplished, on the first time the receiver uses this antenna as an information channel, the code is stored and retained in memory until the radio returns to this time slot whereupon, it is taken from the memory and used as the starting point for the tracking loops. Therefore, the receiver is essentially maintaining three separate sets of receiver parameters, emulating three different receivers, one set of parameters for time slot **1**, a different set for time slot **2** and still a different set for time slot **3**. The distances to antenna B and antenna C can be determined by adding or subtracting the offset, measured in chips, from the absolute range value measured on link AU. Actually the offset is determined before the time slot is used for the first time as an information channel, this determination is made in the process of looking for new paths for handoff. The delay and measure of signal quality is determined and maintained in the potential handoff targets file. These delay offset measurements are also used as additional range measurements in the position location process.

In particular, continuing the above example, the signal **2302** transmitted at antenna A represents a range of 25.5 chips from antenna A to user terminal antenna U. Signal **2304** received at antenna U from antenna A is used as a reference to measure the relative time of arrival of signals from antennas B and C, adjusted for the different time slots in which these signals are placed.

Since timing for time slots **1**, **2** and **3** is sequential, the real time chip patterns for slots **2** and **3** do not overlap. However, after adjustment for time slot delays, the timing relationship is as shown in FIG. 23. Thus adjusted for the time slot difference, signal **2306** received from antenna B at user terminal antenna U, is received in advance (i.e., offset relative to the signal from antenna A) by 8 chips. Similarly, signal **2308** received from antenna C at user terminal U, is also received in advance (i.e., offset relative to the signal from antenna C), but by 6 chips. Received signals may be either delayed or advanced (i.e., have a positive or negative delay) relative to the reference signal **2304**. Receipt in advance indicates that the antenna (B or C) is closer than antenna A. Conversely, a delayed receipt indicates that the antenna (B or C) is further away than antenna A.

In FIG. **23**, the range from antenna B to antenna U is 25.5−8=17.5 chips. In feet, 17.5 chips is 17.5×100=1750 feet, the length of path BU. The range from antenna C to antenna U is 25.5−6=19.5 chips. In feet, 19.5 chips is 19.5×100=1950= path length CU. The user terminal may be located at Z, the intersection of circle A at 2250 feet from antenna A, circle B at 1750 feet from antenna B and circle C at 1950 feet from antenna C.

In the alternative, location measurement may be accomplished by computing the intersection of two hyperbolas. The first hyperbola is the locus of all points having a fixed difference in distance from two foci, which is proportional to the difference in delay between antenna A and antenna B. The second hyperbola is the locus of all points having a fixed difference in distance from two foci, which is proportional to the difference in delay between antenna B and antenna C, (or antenna A and antenna C). Antennas A and B are the foci of the first hyperbola, while antennas B and C are the foci of the second hyperbola. In such manner, subscriber location may be computed without requiring a two way exchange between the user terminal and the transfer station to establish a first range measurement.

LOCATION SERVICES FIGS. 18, 19

Since, the subscriber station receiver is receiving information over three different paths that emanate from known locations, position location information is derived by measuring the time of arrival of messages relative to a fixed time reference. The measurement accuracy depends on the chip rate, but at a chip rate of 10 megachips per second it is quite accurate. There are several ways location measurement and display can be accomplished, depending on how much processing is available in the user terminal. The choice also depends on who will actually use the information. It could be fairly passive, using only the relative chip offset information and obtaining a reference from the current cell. The user could locally derive and display his location, similar to using a GPS satellite. A GPS receiver displays longitude and latitude reading. Location information may also be sent back to a processing center that provides a service to the user. The processing center converts the longitude and latitude coordinates into a location having geographic meaning, such as, a block number on a specific street.

Local geographic position measurement is particularly attractive to people concerned about security and health problems. The manager of the service center could either notify the police, family designate or the service center could include, as part of a special service rate, the staff to check on irregular circumstances. Of course, the service center can also, for a nominal fee, tell an individual his street location and give instructions on how to get to a desired destination address. These services can be provided to users who are pedestrians or moving along in vehicles. The destination instructions can be in the form of a set of one time detailed directions, or specific and continuous intersection prompting as the user travels the suggested route. The prompting could take the form of a voice command, or text display, telling the user to turn right at the next intersection. A delivery truck, cab, ambulance or fire truck could have a special screen that showed a local map with instructions written on it. The instructions can also be modified as the traffic congestion changes. The benefits of the present system are a significant increase in public safety, convenience and productivity.

In the system configurations described previously, the separation between antennas is made sufficient to yield an accurate position location capability. By positioning the antennas to obtain independent paths sufficient to avoid flat fading due to interfering obstacles, then the separation is also sufficient to reduce the triangulation error to a very small number. The incremental cost of including optimization for a location capability is nominal.

Position location processing is accomplished by a third party provider which owns and manages the position location center. Location service can be accomplished in several ways. The preferred approach is to make the user terminal the repository for all location information by building and maintaining a location file. The position location center queries the user terminal over the normal public switched telephone network (preferably packet) when it needed information. Preferably, a provision for encryption during transmission and an access code for privacy is used. The user terminal could also send location information to the location center, also over the public switched telephone network, responsive to user activation. For instance, when the user pushed an alarm button, the radio sends the alarm message, along with the location information, to the location center. The location center would respond according to prearranged directions and the level of subscribed service. Since the user terminal radio develops the code offset information internally, the only additional information the cellular system needs to provide to the user terminal is the distance, one way or round trip, from the user to one of the base station/antennas. The distance information, which would be provided as a service feature to the user, must identify the base station/antenna. All the measurements must be performed within a time window of 100 milliseconds or the error as a result of vehicle movement between measurements could become excessive. For stopped vehicles or pedestrians the time window to perform location measurements could be much longer since there is little or no movement between measurements. Therefore, the distance measurement sent by the system to the user terminal includes the distance in feet, the time in milliseconds and the identity of the measuring entity. Upon receipt of the distance message the user terminal stores the message and makes code offset measurements to several different antennas, and, if signal levels are adequate, stores the composite information in the location file. The location file is retained until a new distance message is received by the user terminal radio, whereupon the user terminal radio again makes the code offset measurements and updates the location file.

When the location center queries the user terminal radio as to its location, the radio sends the contents of the location file. The location center processes this data into very accurate map data, position on a particular street (can be displayed on a typical street map) The system measures distance to the subscriber normally once every minute when the subscriber is in the active receive mode, receiver on, waiting to be paged. The period between measurements is variable and can be adjusted according to the needs of the user. The system sends this new distance to the subscriber station which places it in the file and enters new code offset measurements with it. If the subscriber is engaged in a conversation, the user terminal is transmitting, the base station makes a measurement every ten seconds and if the distance changes more than one hundred feet the system sends a message to the subscriber station. Whenever the user terminal receives a distance measurement it adds the local code offset measurements and updates the file.

It can be seen the user terminals location file is updated at least every minute and more often if warranted. Therefore, the system can know the location of any active user within a distance of approximately 100 feet. Better accuracy and more frequent updating is certainly possible, but due to the loading on the data links the number of subscribers receiving higher performance should be the exception rather than the rule. Whenever the user presses the alarm button on his portable terminal, the terminal transmits the contents of the location file three times which is long enough for the system to read a new distance and send a message to the user terminal. The user terminal makes several offset measurements and sends the new location file three times. The alarm message is repeated every thirty seconds until the battery goes dead. The user terminal radio can have a module added (with its own battery) that emits an audible tone whenever the radio alarm message is transmitted.

The system generates raw location information at the user terminal that needs to be converted into human readable map data. In general, the basic longitude, latitude, or angle and distance readings are fine. However, there is a need for a third party to translate this data into a format that is quickly usable by the mass public, as a service business. Since the user terminal has the basic location information, it can be provided to any authorized entity that requests it from the user terminal. The location processing center periodically queries the subscribed user terminals and maintain a file on their current location. One potential service for subscribers with health problems, is a monitoring system during exercise. If the subscriber stops in an unusual location for an excessive length of time and does not press the alarm button, the location center operator could request life signs or send a medical technician to the paused subscriber. If there is an emergency, the location center operator knows the subscriber location in order to send help. On the other hand, when the alarm button is pressed, the alarm message is addressed to the location center where they are equipped to handle such emergencies. The capability to track user terminals and provide help as the result of some action is useful for many applications. Tracking stolen cars, identifying congestion, keeping ambulances from getting lost and reporting vandalism are but a few examples of the application of the present invention.

The system does, particularly in its distributed configuration as described previously, require a consistent zero time reference across the different base station antennas. Having a zero time reference available significantly reduces the time to resynchronize as the signal hops from antenna to antenna and also aids in the search and handoff process. The location application capability described above allows the system to periodically perform a self calibration by placing several of the user terminals, as described above, at fixed locations and determining the proper zero time setting for these locations. By keeping the correct answer in the central processor, as the system scans these check points, it will get an error indication if the system is out of calibration. The same check points are used to show the effective delay, during the process wherein a variable delay is introduced by incrementing or decrementing the system delay in one or more of the signal paths in the recalibration or adjustment process.

The calibration process could be easily automated. Automation could be implemented in two ways. The first approach is to scan the check points every minute and determine any error that has developed. If this error reaches a significant level the communication system contacts the location center and provides the center with the corrections that need to be factored into the position location calculations. The latter approach requires close coordination between the communication system and the position loca-

tion center. A more autonomous approach would be desirable. The communication system itself could maintain the proper "zero" state by scanning the check points, as described above, and by having the ability to insert or remove delay **1806** in the path to the antenna.

FIG. **18** illustrates a system with self-calibration. Once every minute the system queries each check point **1802**. This results in a distance measure being sent to the check point **1802** where the check point receiver adds the code offset measurements and sends the contents of the location file to the processor **1804** where the received file is compared with a file that contains the correct measurements. If the difference exceeds the threshold the processor **1804** calculates the changes in delay that are required to bring the measurements within tolerance and passes the correction to the controller. The controller maintains a file that includes the variable delay **1806** to be inserted for each antenna. The controller changes the delay entry in the file and a new measurement is taken to validate the calibration. Changes that require significant changes in delay are unlikely, but if this should happen the controller would not initiate any measurements that include the leg that is under recalibration. Thus, the position location capability also provides a service for the communication system. Self calibration results in a significant reduction in installation cost and allows the use of more economical system components.

Location related communications between the antenna devices and the subscriber terminal can be broken into several different links. The functions that are performed by these different links are: 1, distance measurement (requires a two way link, but no traffic); 2, sending measurement information to subscriber terminal (one way data link, except for possible retransmission requests); 3, measuring code offset (only requires user terminal to listen, no data is transferred); 4, Transmit location file to location center or communication processor **1804** (data links can be either one way or two way). Distance measurement can only be performed by the system and since it requires a two way link it can be done while a normal conversation channel has been established or if the terminal is in the listening mode the system has to establish a short round trip connection.

The two way link is required because the base station measures the code phase difference between the signal it sends to, and the signal it receives from, the user terminal. In FIG. **18** the foregoing function is accomplished in processor **1804**. In this sense, the system operates like a radar with a pulse the width of a PN chip. The one way data link message transporting the distance message to the user terminal, is a single message that typically will include an error correcting code, and may also require an acknowledgment message to be sent back from the user terminal to the base station. The acknowledgment message could be sent independently or appended as part of the distance measurement function.

The code offset information is also placed it in a file that is accessible from outside the system. As described previously the user terminal time shares one receiver on the three independent paths that emanate at different times from the three different antennas. Therefore, the receiver tracks three independent paths one after the other. The PN code on each path is the same, and as described above the code has the same starting time at each antenna, but because of the difference in distance to the three different antennas, from the user terminal, the codes arriving at the user terminal are of different code phases. However, since the system cycles very rapidly from antenna to antenna, the receiver cycles between signals received from each of the antennas. Therefore, the receiver maintains three separate starting states and tracking loops for the different time slots. At the end of each time slot, the exact time is known in advance, the previous state is stored in the computer and restored at the beginning of the next time slot assigned to the same antenna. Thus, the processor is emulating three different receivers. The receiver quickly adjusts for any slight drift that occurred while the receiver was locked to the other antennas. Note that the receiver has a specific starting state. Thus, the PN sequence has been shifted to compensate for the difference in range on the path between the user terminal and the first antenna and the path between the user terminal and the second antenna. The difference is the code offset, because the code offset measures the difference in range. Thus, the distance to the second antenna is known without having to do a closed loop (two way) measurement. The same process is followed for the third antenna.

Additional entries, greater than three, in the location file are available using the normal search mode that the user terminal radio uses to identify potential candidates for handoff. The user terminal radio searches the pilot codes emanating from nearby antennas to determine if any of these antennas have better signals than one of the three that are currently being used. If so, the user terminal notifies the system that a good candidate is available. The process of searching starts at the state of the PN signal coming in from time slot number one and if nothing is found at that state the radio adds a chip to the path length and integrates again. The radio keeps adding chips until it finds a signal or exceeds a range threshold. If it exceeds the range threshold it resets the PN generator to a new pilot code and starts at the 0 offset distance again. Therefore, when the radio finds a new pilot signal it knows how many chips it added before it was successful. The added number of chips is also the code offset. The code offset value along with the identity of the code, which uniquely names the antenna, and the time stamp are entered into the location file. The radio places these entries in the location file even if they are not better than the current signals. As the radio scans and finds new antennas it places the four best results in the location file. As it continues to scan, older entries are replaced with newer better entries.

Now that the necessary information is available in the user terminal location file, it may be made available to any authorized requester. Location services may be provided by the communications operator or by a competitive independent service provider. In addition, there will also be large private location centers operated by owners of large fleets. The location center **1902** receives the location files over the public switched network, see FIG. **19**. The network can be a circuit switched network or a packet switched network. A packet switched network is adequate and economical for this type of application.

What is claimed is:

1. In a TDMA/CDMA cellular wireless communication system, wherein a switching center derives a data packet from information received from the public switched network, said data packet communicated to a subscriber station, said system including at least one transfer station between the said switching center and said subscriber station, said transfer station receiving said data packet as a TDMA data packet and retransmitting said TDMA data packet enhanced with a spread spectrum code to said subscriber station, said transfer station including a transfer station TDMA data packet receiver, first and second spread spectrum encoder/modulators, first and second spread spectrum transfer station transmitters and first and second antennas spaced apart from each other, a method at said transfer station comprising:

receiving said TDMA data packet at said transfer station;

spread spectrum modulating said TDMA data packet with a first Pseudo Noise code to form a first spread TDMA/CDMA signal with data packet;

transmitting said first spread TDMA/CDMA signal with data packet from said first antenna to form a first transmitted spread TDMA/CDMA data packet signal in a first time slot;

retrieving from memory said TDMA data packet, after the completion of said first time slot;

spread spectrum modulating said TDMA data packet with a second Pseudo Noise code to form a second spread TDMA/CDMA signal with data packet;

transmitting said second spread TDMA/CDMA signal with data packet from said second antenna to form a second transmitted spread TDMA/CDMA data packet signal after said first transmitted spread TDMA/CDMA data packet signal in a second time slot, said second time slot occurring after said first time slot;

wherein said first and second time slots are selected so that said first antenna and said second antenna do not simultaneously transmit data to said subscriber station; wherein said subscriber station includes a method comprising;

time sharing a single receiver/correlator to demodulate said first spread TDMA/CDMA data packet signal during said first time slot, then time sharing said single receiver/correlator to demodulate said second spread TDMA/CDMA data packet signal during second time slot;

storing detected data bits from said data packet received during said first time slot and then storing detected data bits from said data packet received during said second time slot; and

maximally combining said detected data bits stored during said first time slot with said detected data bits stored during said second time slot.

2. A method in accordance with claim 1, further including a third spread spectrum encoder/modulator, third transfer station spread spectrum transmitter and a third antenna, said method further comprising:

retrieving from memory said TDMA data packet, after the completion of said second time slot;

spread spectrum modulating said TDMA data packet with a third Pseudo Noise code to form a third spread TDMA/CDMA signal with data packet;

transmitting said third spread TDMA/CDMA signal with data packet from said third antenna to form a third transmitted spread TDMA/CDMA data packet signal after said second transmitted spread TDMA/CDMA data packet signal in a third time slot, said third time slot occurring after said second time slot;

wherein said second and third time slots are selected so that said second antenna and said third antenna do not simultaneously transmit data to said subscriber station; wherein said subscriber station includes a method comprising;

time sharing said single receiver/correlator to demodulate said third spread TDMA/CDMA data packet signal during said third time slot;

storing data bits from said data packet received during said third time slot; and

maximally combining said data bits stored during said first time slot with said data bits stored during said second time slot and with said data bits stored during said third time slot.

3. A method in accordance with claim 1, wherein said data packet is communicated from said switching center to said transfer station by a time division multiplex signal, and said data packet is retransmitted from said transfer station to said subscriber station by a code division multiplex signal, said code division multiplex signal being divided into time division multiplex first and second time slots containing said first transmitted spread TDMA/CDMA data packet signal and said second transmitted spread TDMA/CDMA data packet signal from said first and second remotely located independently addressable antennas respectively.

4. A method in accordance with claim 2, wherein said data packet is retransmitted from said transfer station to said subscriber station by a code division multiplex signal, said code division multiplex signal being divided into a third time division multiplex time slot containing said third transmitted spread TDMA data packet signal, from said third antenna.

5. A method in accordance with claim 2, wherein said data packet is communicated from said switching center to said transfer station by a broadband cable television link.

6. A method in accordance with claim 2, wherein said data packet is communicated from said switching center to said transfer station by a fiberoptic cable link.

7. A method in accordance with claim 2, wherein said data packet is communicated from said switching center to said transfer station by a pair-gain module telephone link.

8. A method in accordance with claim 2, wherein said data packet is communicated from said switching center to said transfer station by a twisted pair wire loop telephone link.

9. A method in accordance with claim 1, further including a carrier frequency having a characteristic wavelength, wherein said first and second antennas are spaced apart from each other by a distance of at least one wavelength of the carrier frequency.

10. A method in accordance with claim 2, wherein said data packet is communicated from said switching center to a base station by a time division multiplex signal, and said data packet is retransmitted from said base station to said transfer station by a time division multiplex signal, and said data packet is retransmitted from said transfer station to said subscriber station by a code division multiplex signal, said code division multiplex signal being divided into time division multiplex first and second time slots containing said first transmitted CDMA data packet and said second transmitted CDMA data packet, from said first and second antenna respectively.

11. A method in accordance with claim 10, wherein said data packet is communicated from said base station to said transfer station by a time division digital radio link.

12. A method in accordance with claim 10, wherein said data packet is communicated from said switching center to said base station by a broadband cable television link.

13. A method in accordance with claim 10, wherein said data packet is communicated from said switching center to said base station by a fiberoptic cable link.

14. A method in accordance with claim 10, wherein said data packet is communicated from said switching center to said base station by a pair-gain module telephone link.

15. A method in accordance with claim 10, wherein said data packet is communicated from said switching center to said base station by a twisted pair wire loop telephone link.

16. In a TDMA/CDMA cellular wireless communication system, wherein a switching center/central processor derives a data packet from information received from the public switched network, said data packet communicated to a subscriber station, said subscriber station receiving said data packet as a TDMA data packet on a broadcast frequency from an over the air transmission, said TDMA data packet

enhanced for over the air transmission with a CDMA spread spectrum modulation, and further including a wideband cable distribution network having a cable distribution headend coupled via a wideband transmission cable to a plurality of spaced apart antennas, said system including at least one centrally located transfer station at said cable distribution headend, said transfer station adapted for receiving said TDMA data packet from either a base station or said switching center/central processor, bandspreading said TDMA data packet with a CDMA spreading code to form a spread TDMA/CDMA signal and distributing said spread TDMA/CDMA signal by said wideband transmission cable, said wideband cable distribution network further including a first remotely located independently addressable antenna and a second remotely located independently addressable antenna disposed at first and second locations spaced apart on said wideband distribution cable respectively, a method comprising:

receiving said TDMA data packet at said centrally located transfer station;

enhancing said TDMA data packet with spread spectrum modulation, using a first spreading code, to form a first spread TDMA/CDMA signal;

distributing said first spread TDMA/CDMA signal from said centrally located transfer station to said first remotely located independently addressable antenna on a first carrier frequency on said wideband transmission cable;

receiving said first spread TDMA/CDMA signal at said first remotely located independently addressable antenna on said first carrier frequency;

translating said first spread TDMA/CDMA signal from said first carrier frequency on said wideband transmission cable to said broadcast frequency for over the air transmission;

amplifying and transmitting said first spread TDMA/CDMA signal from said first remotely located independently addressable antenna on said broadcast frequency for over the air transmission to form a first transmitted spread TDMA/CDMA data packet signal in a first time slot; and

enhancing said TDMA data packet with spread spectrum modulation, using a second spreading code, to form a second spread TDMA/CDMA signal;

distributing said second spread TDMA/CDMA signal from said centrally located transfer station to said second remotely located independently addressable antenna on a second carrier frequency on said wideband transmission cable;

receiving said second spread TDMA/CDMA signal at said second remotely located independently addressable antenna on said second cable carrier frequency;

translating said second spread TDMA/CDMA signal from said second carrier frequency on said wideband transmission cable to said broadcast frequency for over the air transmission;

amplifying and transmitting said second spread TDMA/CDMA signal from said second remotely located independently addressable antenna on said broadcast frequency for over the air transmission to form a second transmitted spread TDMA/CDMA data packet signal after said first transmitted spread TDMA/CDMA data packet signal in a second time slot, said second time slot occurring after said first time slot;

wherein said first and second time slots are selected so that said first antenna and said second antenna do not simultaneously transmit data to said subscriber station; where said subscriber station includes a method comprising;

time sharing a single receiver/correlator to demodulate first spread TDMA/CDMA signal during said first time slot, then time sharing said single receiver/correlator to demodulate said second spread TDMA/CDMA data packet signal during said second time slot;

storing detected data bits from said data packet received during said first time slot and then storing detected data bits from said data packet received during said second time slot; and

maximally combining said detected data bits stored during said first time slot with said detected data bits stored during said second time slot.

17. In a TDMA/CDMA cellular wireless communication system in accordance with claim **16**, further including a third remotely located independently addressable antenna, said method comprising,

enhancing said TDMA data packet with spread spectrum modulation, using a third spreading code, to form a third spread TDMA/CDMA signal;

distributing said third spread TDMA/CDMA signal from said centrally located transfer station to said third remotely located independently addressable antenna on a third carrier frequency on said wideband transmission cable;

receiving said third spread TDMA/CDMA signal at said third remotely located independently addressable antenna on said third carrier frequency;

translating said third spread TDMA/CDMA signal from said third carrier frequency on said wideband transmission cable to said broadcast frequency for over the air transmission;

amplifying and transmitting said third spread TDMA/CDMA signal from said third remotely located independently addressable antenna on said broadcast frequency for over the air transmission to form a third transmitted spread TDMA/CDMA data packet signal in a third time slot, said third time slot occurring after said second time slot;

wherein said second and third time slots are selected so that said second antenna and said third antenna do not simultaneously transmit data to said subscriber station; wherein said subscriber station includes a method comprising;

time sharing said single receiver/correlator to demodulate said third spread TDMA/CDMA data packet signal during said third time slot;

storing detected data bits from said TDMA data packet received during said third time slot; and maximally combining said detected data bits stored during said first time slot with said detected data bits stored during said second time slot, and with said detected data bits stored during said third time slot.

18. A method in accordance with claim **17**, wherein said system includes a plurality of said centrally located transfer stations, each said centrally located transfer station adding a user unique CDMA spread spectrum code to said TDMA data packet to form a spread TDMA/CDMA data packet signal, said user unique CDMA spread spectrum code assigned during an initial call setup process.

19. A method in accordance with claim **18**, wherein said transfer station assigns multiple unique CDMA spreading codes to said user, unique spreading code one to be applied during said first time slot, unique spreading code N to be applied during time slot N, where N is 1 to 32.

20. A method in accordance with claim 18, wherein said transfer station assigns a single unique CDMA code to a user, but derives different long code segments for each time slot by allowing the long Pseudo Noise code to continue to run.

21. A method in accordance with claim 17, wherein said subscriber station utilizes said single time shared receiver/correlator for demodulating other spread signals during time slots not assigned to user data traffic.

22. A method in accordance with claim 21, wherein said other spread signals could be a plurality of transfer station or base station control channels, said other spread spectrum signals could assist in hand-off process.

23. A method in accordance with claim 17, wherein said transfer station is centrally located and said spread TDMA/CDMA data packet signals are communicated to said subscriber station by a network of said remote antennas, said remote antennas connected to said transfer station by said wideband transmission cable.

24. A method in accordance with claim 23, wherein said TDMA/CDMA packet is communicated from said transfer station to said antenna by frequency division multiplex, with assigned time slots, over said wideband transmission cable.

25. A method in accordance with claim 17, wherein said transfer station is centrally located and said TDMA/CDMA data packet is communicated to said subscriber station by a network of said remote antennas, said remote antennas connected to said transfer station by wideband telephone lines.

26. A method in accordance with claim 17, wherein said system further includes a base station between said switching center/central processor and said transfer station, said base station receives basic TDMA data packet from said switching center/central processor, processes and formats the basic TDMA data packet for over the air transmission and transmits said TDMA data packet from base station antenna to said transfer station.

27. A method in accordance with claim 16, wherein said spaced apart remote antennas are separated by sufficient distance for each separated antenna to form a new cell for the system.

28. A method in accordance with claim 26, wherein said base station is centrally located with the said centrally located transfer station, said centrally located base station communicating to said centrally located transfer station over a wideband transmission cable.

29. A method in accordance with claim 17, wherein said centrally located base station is further integrated with centrally located transfer station to form a base-transfer station, said base-transfer station receives a TDMA data packet from said switching center/central processor, formats said TDMA data packet, spreads formatted TDMA data packet to form a spread formatted TDMA/CDMA data packet to be transmitted over wideband transmission cable to said remote antennas, said remote antennas retransmit said spread formatted TDMA/CDMA data packet over the air to said subscriber station.

30. A method in accordance with claim 17, wherein said transfer station is centrally located and said TDMA/CDMA packet is communicated to said subscriber station by a network of remote antennas, said remote antennas connected to said transfer station by wide band telephone lines.

31. A method in accordance to claim 24, wherein said frequency division multiplex is further enhanced to include frequency hopping mode.

32. A method in accordance with claim 25, wherein said TDMA/CDMA packet is communicated from said transfer station to said antenna by frequency division multiplex over said wideband telephone lines.

33. In a TDMA/CDMA cellular wireless communication system, wherein a switching center derives a data packet from information received from the public switched network, said data packet communicated to a subscriber station, said system including at least one transfer station between the said switching center and said subscriber station, said transfer station receiving said data packet as a TDMA data packet and retransmitting said TDMA data packet enhanced with a spread spectrum code to said subscriber station, said transfer station including a transfer station TDMA data packet receiver, first and second spread spectrum encoder/modulators, first and second spread spectrum transfer station transmitters and first and second antennas spaced apart from each other, an apparatus at said transfer station comprising:

means for receiving said TDMA data packet at said transfer station;

means for spread spectrum modulating said TDMA data packet with a first Pseudo Noise code to form a first spread TDMA/CDMA signal with data packet;

means for transmitting said first spread TDMA/CDMA signal with data packet from said first antenna to form a first transmitted spread TDMA/CDMA data packet signal in a first time slot;

means for retrieving from memory said TDMA data packet, after the completion of said first time slot;

means for spread spectrum modulating said TDMA data packet with a second Pseudo Noise code to form a second spread TDMA/CDMA signal with data packet;

means for transmitting said second spread TDMA/CDMA signal with data packet from said second antenna to form a second transmitted spread TDMA/CDMA data packet signal after said first transmitted spread TDMA/CDMA data packet signal in a second time slot, said second time slot occurring after said first time slot;

wherein said first and second time slots are selected so that said first antenna and said second antenna do not simultaneously transmit data to said subscriber station; wherein said subscriber station includes an apparatus comprising;

means for time sharing a single receiver/correlator to demodulate said first spread TDMA/CDMA data packet signal during said first time slot, then time sharing said single receiver/correlator to demodulate said second spread TDMA/CDMA data packet signal during second time slot;

means for storing detected data bits from said data packet received during said first time slot and then storing detected data bits from said data packet received during said second time slot; and

means for maximally combining said detected data bits stored during said first time slot with said detected data bits stored during said second time slot.

34. An apparatus in accordance with claim 33, further including a third spread spectrum encoder/modulator, third transfer station spread spectrum transmitter and a third antenna, said apparatus further comprising:

means for retrieving from memory said TDMA data packet, after the completion of said second time slot;

means for spread spectrum modulating said TDMA data packet with a third Pseudo Noise code to form a third spread TDMA/CDMA signal with data packet;

means for transmitting said third spread TDMA/CDMA signal with data packet from said third antenna to form

a third transmitted spread TDMA/CDMA data packet signal after said second transmitted spread TDMA/CDMA data packet signal in a third time slot, said third time slot occurring after said second time slot;

wherein said second and third time slots are selected so that said second antenna and said third antenna do not simultaneously transmit data to said subscriber station; wherein said subscriber station includes an apparatus comprising;

means for time sharing said single receiver/correlator to demodulate said third spread TDMA/CDMA data packet signal during said third time slot;

means for storing data bits from said data packet received during said third time slot; and

means for maximally combining said data bits stored during said first time slot with said data bits stored during said second time slot and with said data bits stored during said third time slot.

35. An apparatus in accordance with claim 33, wherein said data packet is communicated from said switching center to said transfer station by a time division multiplex signal, and said data packet is retransmitted from said transfer station to said subscriber station by a code division multiplex signal, said code division multiplex signal being divided into time division multiplex first and second time slots containing said first transmitted spread TDMA/CDMA data packet signal and said second transmitted spread TDMA/CDMA data packet signal from said first and second remotely located independently addressable antennas respectively.

36. An apparatus in accordance with claim 34, wherein said data packet is retransmitted from said transfer station to said subscriber station by a code division multiplex signal, said code division multiplex signal being divided into a third time division multiplex time slot containing said third transmitted spread TDMA data packet signal, from said third antenna.

37. An apparatus in accordance with claim 34, wherein said data packet is communicated from said switching center to said transfer station by a broadband cable television link.

38. An apparatus in accordance with claim 34, wherein said data packet is communicated from said switching center to said transfer station by a fiberoptic cable link.

39. An apparatus in accordance with claim 34, wherein said data packet is communicated from said switching center to said transfer station by a pair-gain module telephone link.

40. An apparatus in accordance with claim 34, wherein said data packet is communicated from said switching center to said transfer station by a twisted pair wire loop telephone link.

41. An apparatus in accordance with claim 33, further including a carrier frequency having a characteristic wavelength, wherein said first and second antennas are spaced apart from each other by a distance of at least one wavelength of the carrier frequency.

42. An apparatus in accordance with claim 34, wherein said data packet is communicated from said switching center to a base station by a time division multiplex signal, and said data packet is retransmitted from said base station to said transfer station by a time division multiplex signal, and said data packet is retransmitted from said transfer station to said subscriber station by a code division multiplex signal, said code division multiplex signal being divided into time division multiplex first and second time slots containing said first transmitted CDMA data packet and said second transmitted CDMA data packet, from said first and second antenna respectively.

43. An apparatus in accordance with claim 42, wherein said data packet is communicated from said base station to said transfer station by a time division digital radio link.

44. An apparatus in accordance with claim 42, wherein said data packet is communicated from said switching center to said base station by a broadband cable television link.

45. An apparatus in accordance with claim 42, wherein said data packet is communicated from said switching center to said base station by a fiberoptic cable link.

46. An apparatus in accordance with claim 42, wherein said data packet is communicated from said switching center to said base station by a pair-gain module telephone link.

47. An apparatus in accordance with claim 42, wherein said data packet is communicated from said switching center to said base station by a twisted pair wire loop telephone link.

48. In a TDMA/CDMA cellular wireless communication system, wherein a switching center/central processor derives a data packet from information received from the public switched network, said data packet communicated to a subscriber station, said subscriber station receiving said data packet as a TDMA data packet on a broadcast frequency from an over the air transmission, said TDMA data packet enhanced for over the air transmission with a CDMA spread spectrum modulation, and further including a wideband cable distribution network having a cable distribution headend coupled via a wideband transmission cable to a plurality of spaced apart antennas, said system including at least one centrally located transfer station at said cable distribution headend, said transfer station adapted for receiving said TDMA data packet from either a base station or said switching center/central processor, bandspreading said TDMA data packet with a CDMA spreading code to form a spread TDMA/CDMA signal and distributing said spread TDMA/CDMA signal by said wideband transmission cable, said wideband cable distribution network further including a first remotely located independently addressable antenna and a second remotely located independently addressable antenna disposed at first and second locations spaced apart on said wideband distribution cable respectively, an apparatus comprising:

means for receiving said TDMA data packet at said centrally located transfer station;

means for enhancing said TDMA data packet with spread spectrum modulation, using a first spreading code, to form a first spread TDMA/CDMA signal; means for

means for distributing said first spread TDMA/CDMA signal from said centrally located transfer station to said first remotely located independently addressable antenna on a first carrier frequency on said wideband transmission cable;

means for receiving said first spread TDMA/CDMA signal at said first remotely located independently addressable antenna on said first carrier frequency;

means for translating said first spread TDMA/CDMA signal from said first carrier frequency on said wideband transmission cable to said broadcast frequency for over the air transmission;

means for amplifying and transmitting said first spread TDMA/CDMA signal from said first remotely located independently addressable antenna on said broadcast frequency for over the air transmission to form a first transmitted spread TDMA/CDMA data packet signal in a first time slot; and

means for enhancing said TDMA data packet with spread spectrum modulation, using a second spreading code, to form a second spread TDMA/CDMA signal;

means for distributing said second spread TDMA/CDMA signal from said centrally located transfer station to

said second remotely located independently addressable antenna on a second carrier frequency on said wideband transmission cable;

means for receiving said second spread TDMA/CDMA signal at said second remotely located independently addressable antenna on said second cable carrier frequency;

means for translating said second spread TDMA/CDMA signal from said second carrier frequency on said wideband transmission cable to said broadcast frequency for over the air transmission;

means for amplifying and transmitting said second spread TDMA/CDMA signal from said second remotely located independently addressable antenna on said broadcast frequency for over the air transmission to form a second transmitted spread TDMA/CDMA data packet signal after said first transmitted spread TDMA/CDMA data packet signal in a second time slot, said second time slot occurring after said first time slot;

wherein said first and second time slots are selected so that said first antenna and said second antenna do not simultaneously transmit data to said subscriber station; where said subscriber station includes an apparatus comprising;

means for time sharing a single receiver/correlator to demodulate first spread TDMA/CDMA signal during said first time slot, then time sharing said single receiver/correlator to demodulate said second spread TDMA/CDMA data packet signal during said second time slot;

means for storing detected data bits from said data packet received during said first time slot and then storing detected data bits from said data packet received during said second time slot; and

means for maximally combining said detected data bits stored during said first time slot with said detected data bits stored during said second time slot.

49. In a TDMA/CDMA cellular wireless communication system in accordance with claim 46, further including a third remotely located independently addressable antenna, said apparatus comprising,

means for enhancing said TDMA data packet with spread spectrum modulation, using a third spreading code, to form a third spread TDMA/CDMA signal;

means for distributing said third spread TDMA/CDMA signal from said centrally located transfer station to said third remotely located independently addressable antenna on a third carrier frequency on said wideband transmission cable;

means for receiving said third spread TDMA/CDMA signal at said third remotely located independently addressable antenna on said third carrier frequency;

means for translating said third spread TDMA/CDMA signal from said third carrier frequency on said wideband transmission cable to said broadcast frequency for over the air transmission;

means for amplifying and transmitting said third spread TDMA/CDMA signal from said third remotely located independently addressable antenna on said broadcast frequency for over the air transmission to form a third transmitted spread TDMA/CDMA data packet signal in a third time slot, said third time slot occurring after said second time slot;

wherein said second and third time slots are selected so that said second antenna and said third antenna do not simultaneously transmit data to said subscriber station; wherein said subscriber station includes an apparatus comprising;

means for time sharing said single receiver/correlator to demodulate said third spread TDMA/CDMA data packet signal during said third time slot;

means for storing detected data bits from said TDMA data packet received during said third time slot; and

means for maximally combining said detected data bits stored during said first time slot with said detected data bits stored during said second time slot, and with said detected data bits stored during said third time slot.

50. An apparatus in accordance with claim 49, wherein said system includes a plurality of said centrally located transfer stations, each said centrally located transfer station adding a user unique CDMA spread spectrum code to said TDMA data packet to form a spread TDMA/CDMA data packet signal, said user unique CDMA spread spectrum code assigned during an initial call setup process.

51. An apparatus in accordance with claim 50, wherein said transfer station assigns multiple unique CDMA spreading codes to said user, unique spreading code one to be applied during said first time slot, unique spreading code N to be applied during time slot N, where N is 1 to 32.

52. An apparatus in accordance with claim 50, wherein said transfer station assigns a single unique CDMA code to a user, but derives different long code segments for each time slot by allowing the long Pseudo Noise code to continue to run.

53. An apparatus in accordance with claim 49, wherein said subscriber station utilizes said single time shared receiver/correlator for demodulating other spread signals during time slots not assigned to user data traffic.

54. An apparatus in accordance with claim 53, wherein said other spread signals could be a plurality of transfer station or base station control channels, said other spread spectrum signals could assist in hand-off process.

55. An apparatus in accordance with claim 49, wherein said transfer station is centrally located and said spread TDMA/CDMA data packet signals are communicated to said subscriber station by a network of said remote antennas, said remote antennas connected to said transfer station by said wideband transmission cable.

56. An apparatus in accordance with claim 55, wherein said TDMA/CDMA packet is communicated from said transfer station to said antenna by frequency division multiplex, with assigned time slots, over said wideband transmission cable.

57. An apparatus in accordance with claim 49, wherein said transfer station is centrally located and said TDMA/CDMA data packet is communicated to said subscriber station by a network of said remote antennas, said remote antennas connected to said transfer station by wideband telephone lines.

58. An apparatus in accordance with claim 49, wherein said system further includes a base station between said switching center/central processor and said transfer station, said base station receives basic TDMA data packet from said switching center/central processor, processes and formats the basic TDMA data packet for over the air transmission and transmits said TDMA data packet from base station antenna to said transfer station.

59. An apparatus in accordance with claim 48, wherein said spaced apart remote antennas are separated by sufficient distance for each separated antenna to form a new cell for the system.

60. An apparatus in accordance with claim 58, wherein said base station is centrally located with the said centrally located transfer station, said centrally located base station communicating to said centrally located transfer station over a wideband transmission cable.

61. An apparatus in accordance with claim 49, wherein said centrally located base station is further integrated with centrally located transfer station to form a base-transfer station, said base-transfer station receives a TDMA data packet from said switching center/central processor, formats said TDMA data packet, spreads formatted TDMA data packet to form a spread formatted TDMA/CDMA data packet to be transmitted over wideband transmission cable to said remote antennas, said remote antennas retransmit said spread formatted TDMA/CDMA data packet over the air to said subscriber station.

62. An apparatus in accordance with claim 49, wherein said transfer station is centrally located and said TDMA/CDMA packet is communicated to said subscriber station by a network of remote antennas, said remote antennas connected to said transfer station by wide band telephone lines.

63. An apparatus in accordance to claim 56, wherein said frequency division multiplex is further enhanced to include frequency hopping mode.

64. An apparatus in accordance with claim 57, wherein said TDMA/CDMA packet is communicated from said transfer station to said antenna by frequency division multiplex over said wideband telephone lines.

* * * * *

US005363403A

United States Patent [19]

Schilling et al.

[11] Patent Number: 5,363,403

[45] Date of Patent: Nov. 8, 1994

[54] SPREAD SPECTRUM CDMA SUBTRACTIVE INTERFERENCE CANCELER AND METHOD

[75] Inventors: **Donald L. Schilling**, Sands Point; **John Kowalski**, New York, both of N.Y.

[73] Assignee: **InterDigital Technology Corporation**, Wilmington, Del.

[21] Appl. No.: **51,017**

[22] Filed: **Apr. 22, 1993**

[51] **Int. Cl.**^{5} **H04K 1/00**

[52] **U.S. Cl.** 375/1; 380/34

[58] **Field of Search** 375/1; 380/34

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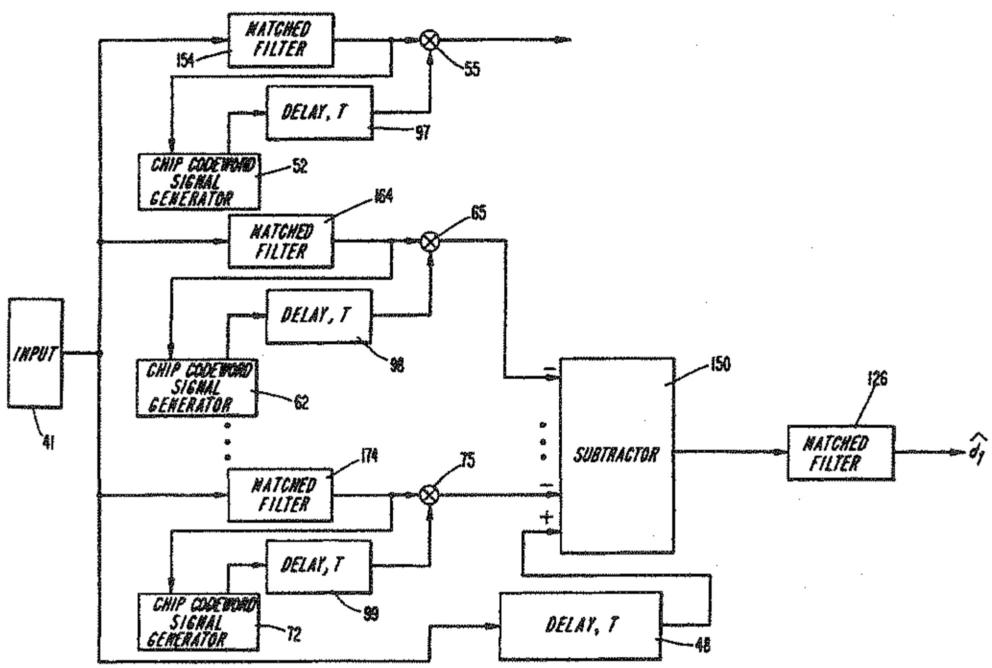
Primary Examiner—Tod R. Swann

Attorney, Agent, or Firm—David Newman & Associates

[57] ABSTRACT

A spread-spectrum code division multiple access interference canceler for reducing interference in a direct sequence CDMA receiver having N chip-code channels. The interference canceler includes a plurality of correlators or matched filters, a plurality of spread-spectrum-processing circuits, subtracting circuits, and channel correlators or channel-matched filters. Using a plurality of chip-code signals, the plurality of correlators despreads the spread-spectrum CDMA signal as a plurality of despread signals, respectively. The plurality of spread-spectrum-processing circuits uses a timed version of the plurality of chip-code signals, for spread-spectrum processing the plurality of despread signals, respectively, with a chip-code-signal corresponding to a respective despread signal. For recovering a code channel using an i^{th} chip-code-signal, the subtracting circuits subtracts from the spread-spectrum CDMA signal, each of the N-1 spread-spectrum-processed-despread signals thereby generating a subtracted signal. The N-1 spread-spectrum-processed-despread signals do not include the spread-spectrum-processed-despread signal of the i^{th} channel of the spread-spectrum CDMA signal. The channel correlator or channel-matched filter despreads the subtracted signal.

25 Claims, 8 Drawing Sheets



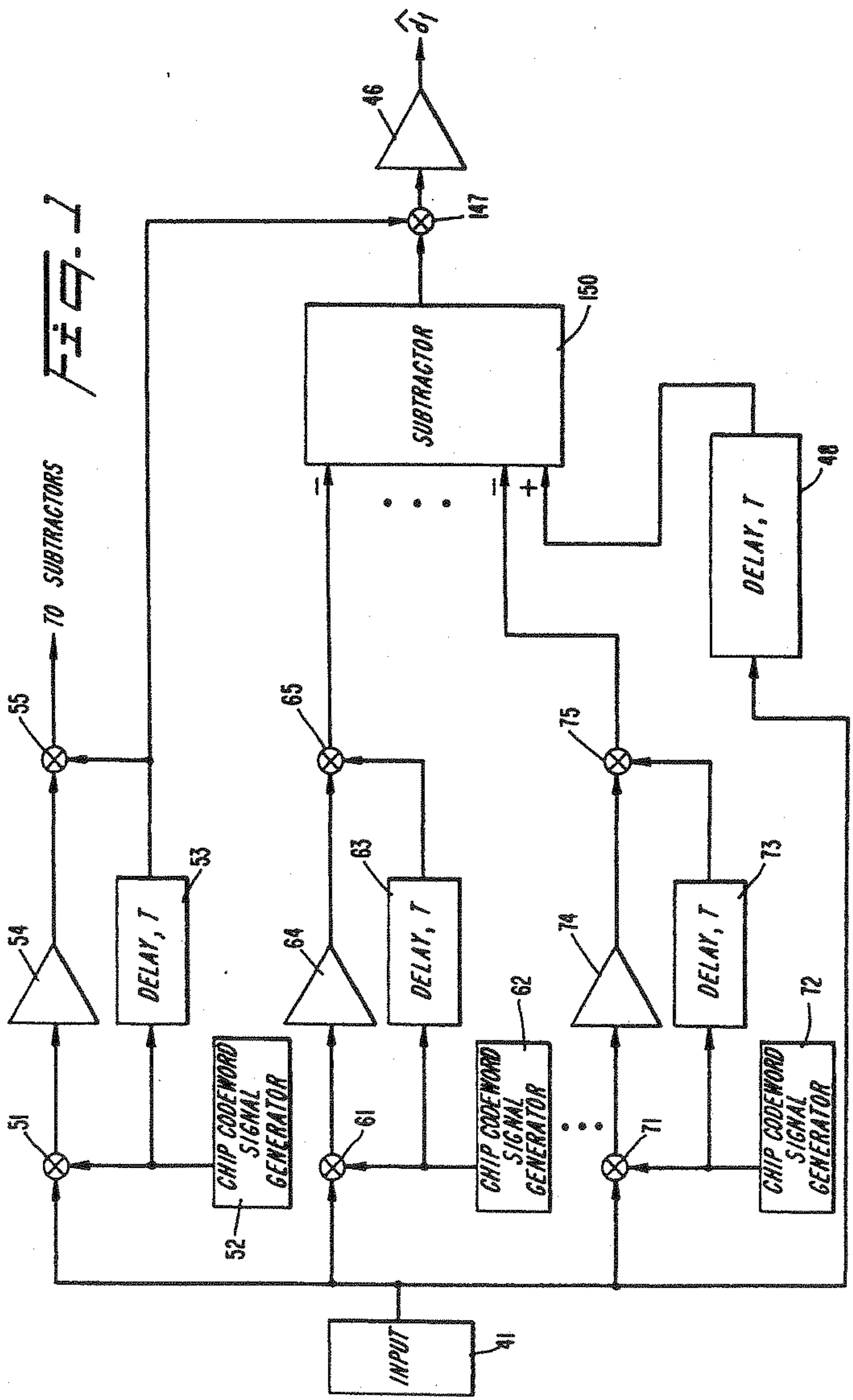

SUBTRACTOR
DELAY, T
DELAY, T
DELAY, T
DELAY, T
CHIP CODEWORD SIGNAL GENERATOR
CHIP CODEWORD SIGNAL GENERATOR
CHIP CODEWORD SIGNAL GENERATOR
INPUT
TO SUBTRACTORS
41
46
48
51
52
53
54
55
61
62
63
64
65
71
72
73
74
75
147
150

FIG. 1

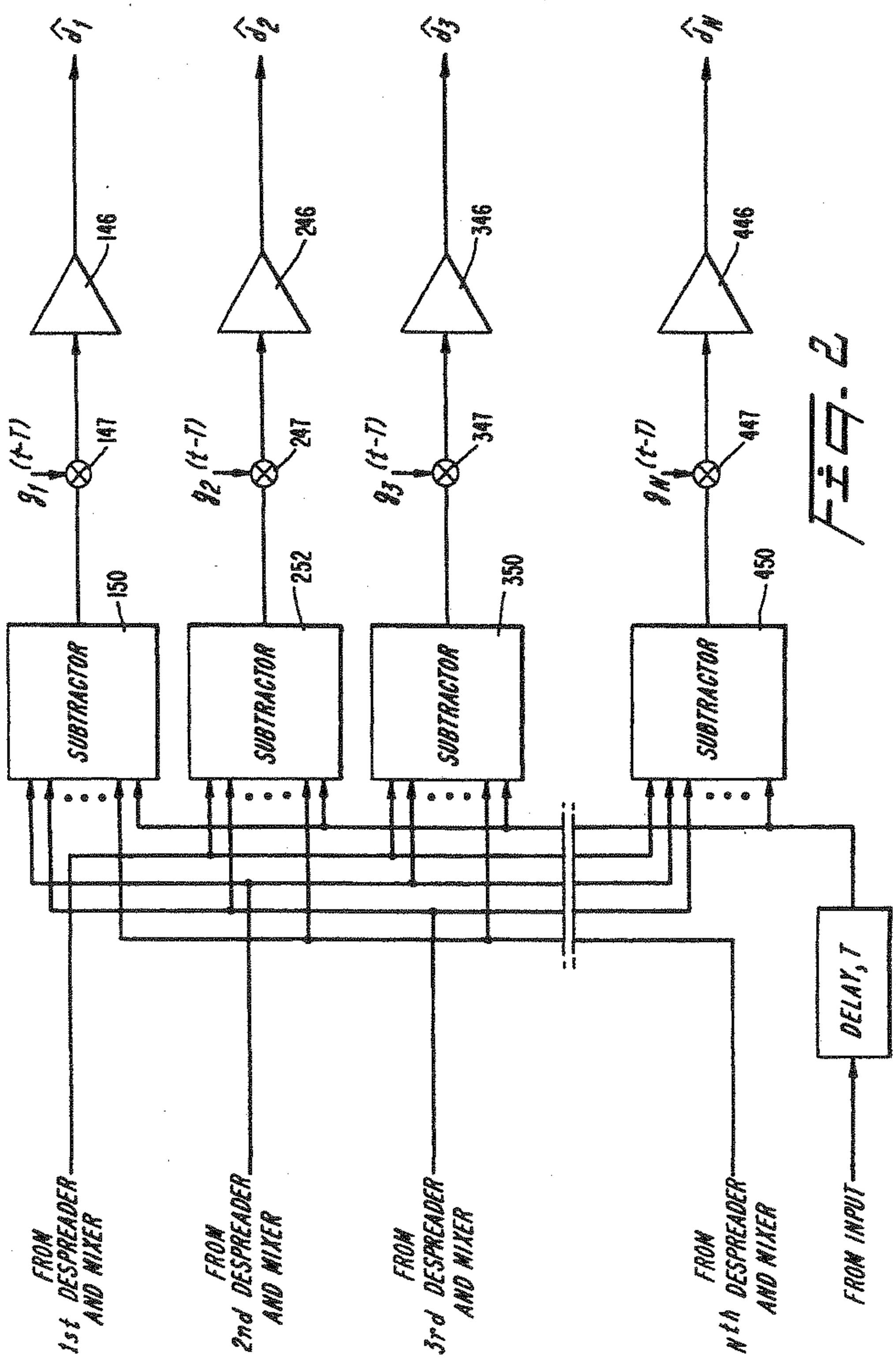

FROM 1st DESPREADER AND MIXER
FROM 2nd DESPREADER AND MIXER
FROM 3rd DESPREADER AND MIXER
FROM Nth DESPREADER AND MIXER
FROM INPUT
DELAY, T
SUBTRACTOR
SUBTRACTOR
SUBTRACTOR
SUBTRACTOR
150
252
350
450
$g_1(t-T)$
$g_2(t-T)$
$g_3(t-T)$
$g_N(t-T)$
147
247
347
447
146
246
346
446
$\hat{d}_1$
$\hat{d}_2$
$\hat{d}_3$
$\hat{d}_N$

FIG. 2

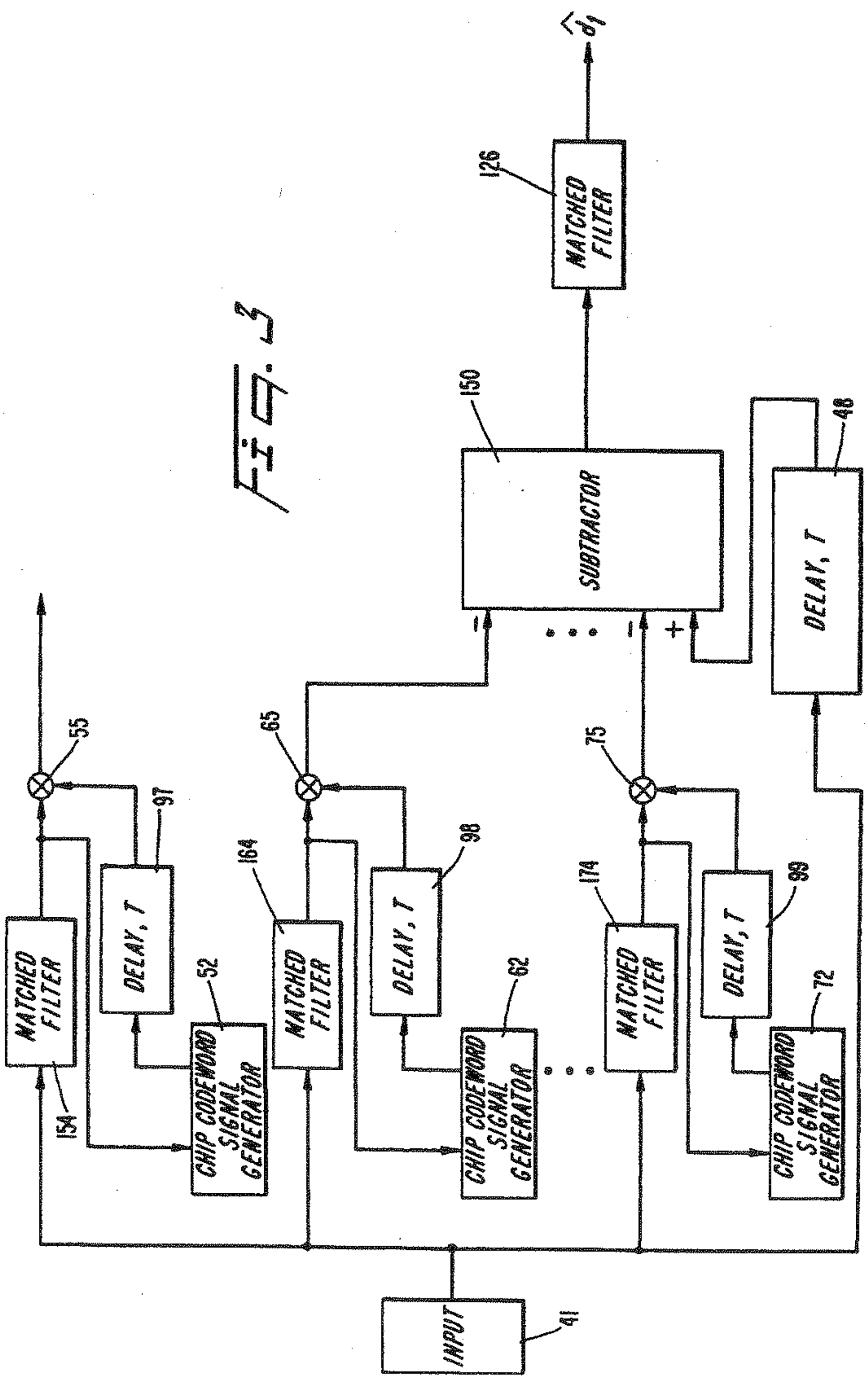
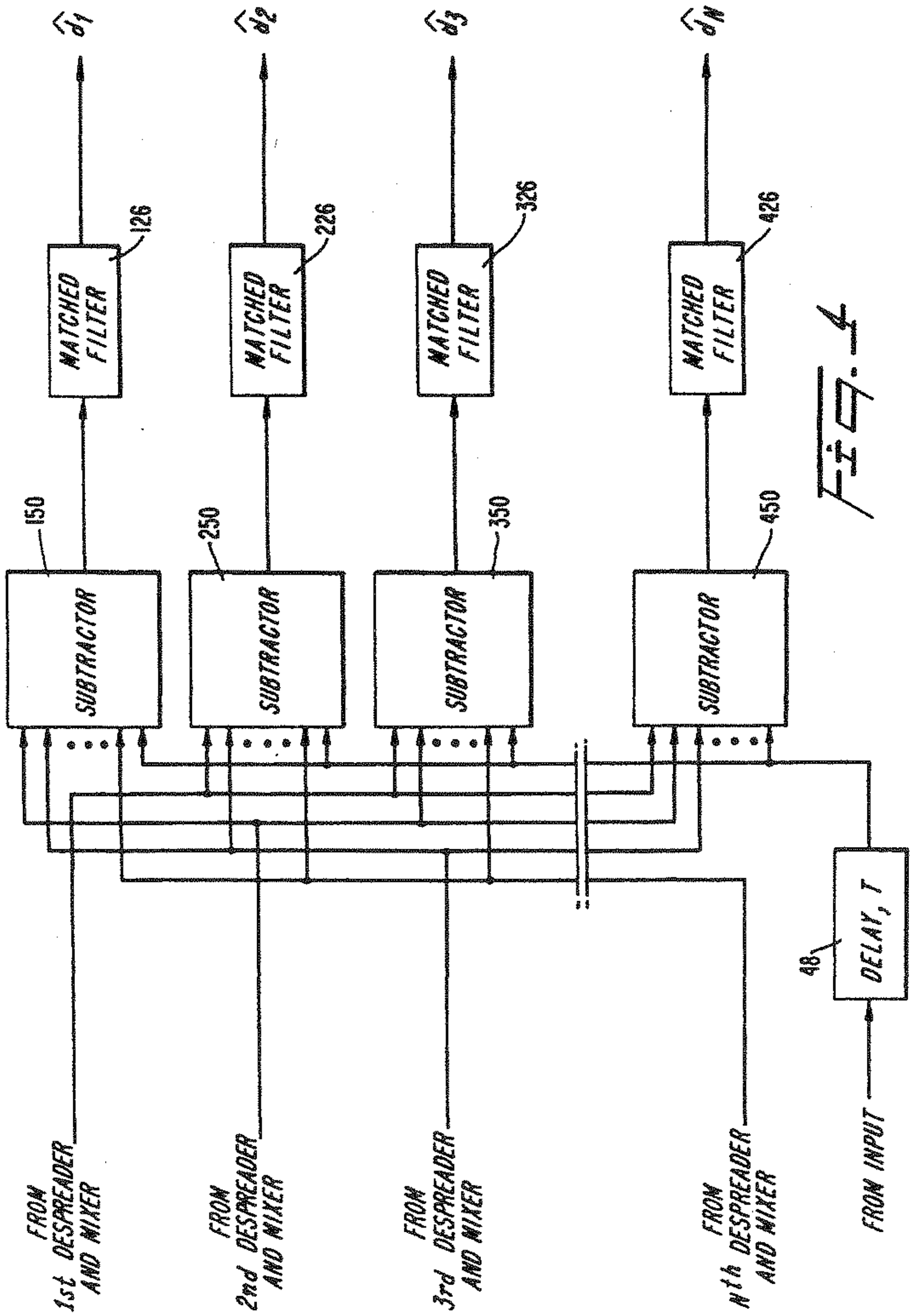

$\hat{d}_1$
126
MATCHED FILTER
150
SUBTRACTOR
48
DELAY, T
55
97
MATCHED FILTER
DELAY, T
52
CHIP CODEWORD SIGNAL GENERATOR
154
65
164
98
MATCHED FILTER
DELAY, T
62
CHIP CODEWORD SIGNAL GENERATOR
75
174
99
MATCHED FILTER
DELAY, T
72
CHIP CODEWORD SIGNAL GENERATOR
INPUT
41

FIG. 3



$\hat{d}_1$
$\hat{d}_2$
$\hat{d}_3$
$\hat{d}_N$
MATCHED FILTER
126
MATCHED FILTER
226
MATCHED FILTER
326
MATCHED FILTER
426
150
SUBTRACTOR
250
SUBTRACTOR
350
SUBTRACTOR
450
SUBTRACTOR
48
DELAY, T
FROM 1st DESPREADER AND MIXER
FROM 2nd DESPREADER AND MIXER
FROM 3rd DESPREADER AND MIXER
FROM Nth DESPREADER AND MIXER
FROM INPUT

FIG. 4

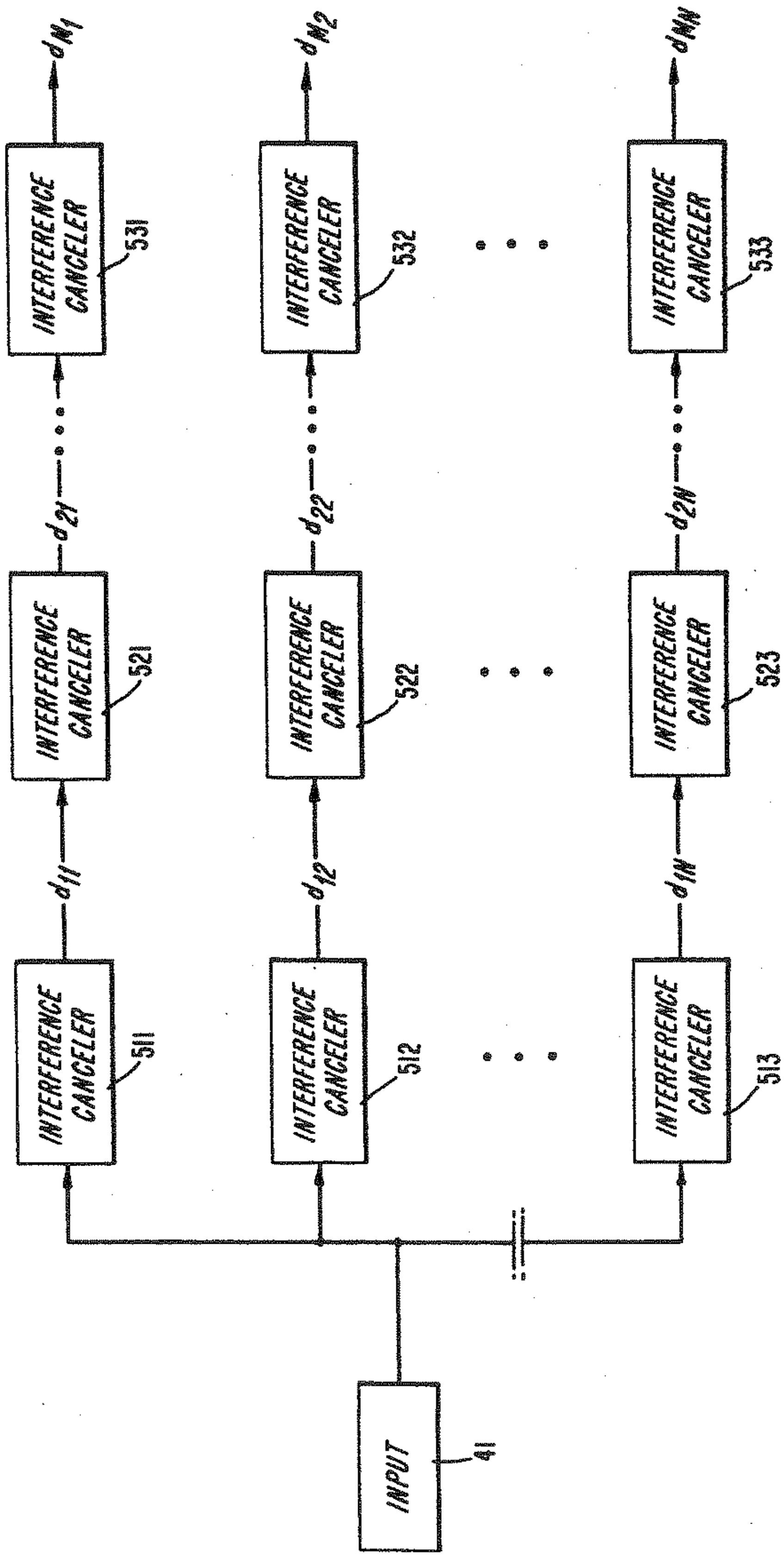

INPUT
41
INTERFERENCE CANCELER
511
INTERFERENCE CANCELER
512
INTERFERENCE CANCELER
513
d_{11}
d_{12}
d_{1N}
INTERFERENCE CANCELER
521
INTERFERENCE CANCELER
522
INTERFERENCE CANCELER
523
d_{21}
d_{22}
d_{2N}
INTERFERENCE CANCELER
531
INTERFERENCE CANCELER
532
INTERFERENCE CANCELER
533
d_{M1}
d_{M2}
d_{MN}

FIG. 5

Fig. 6

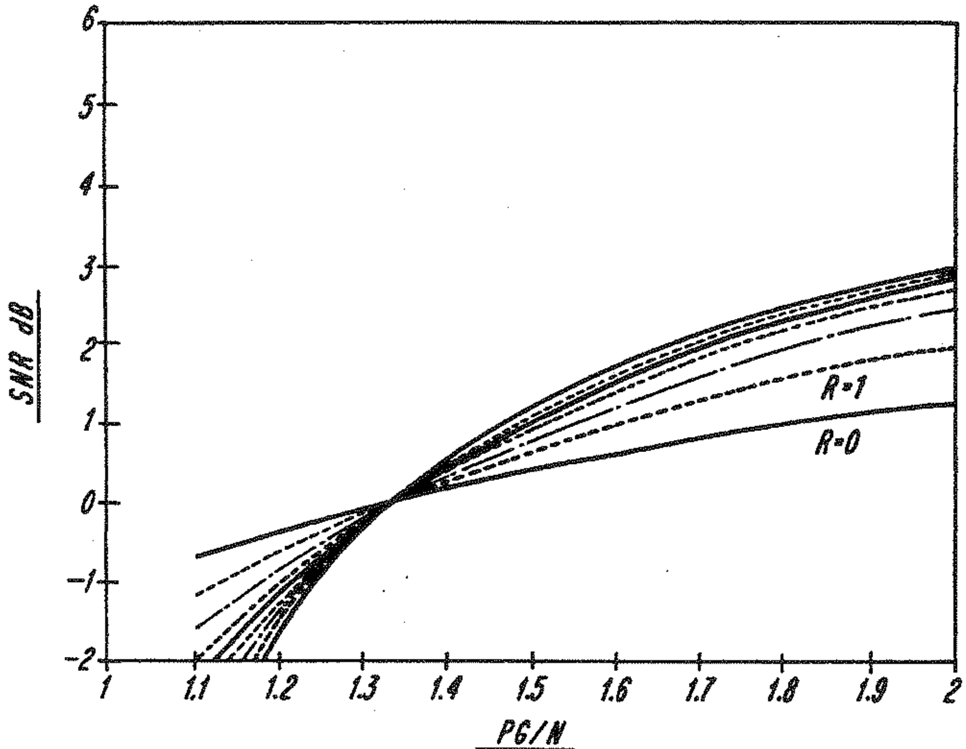

6
5
4
3
2
1
0
-1
-2
SNR dB
R=1
R=0
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

Fig. 7

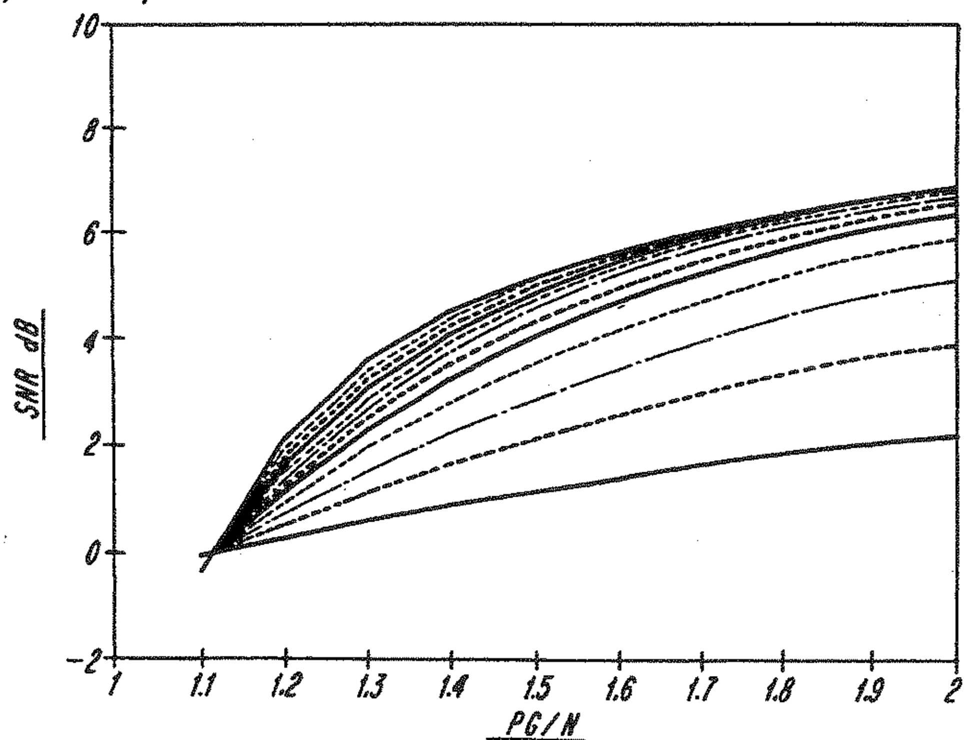
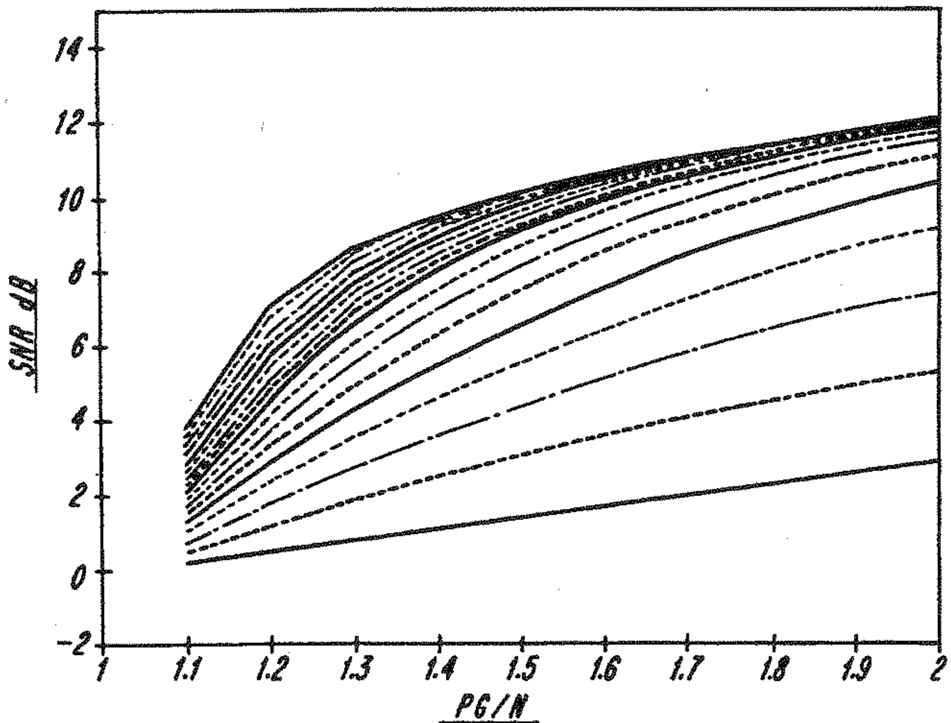
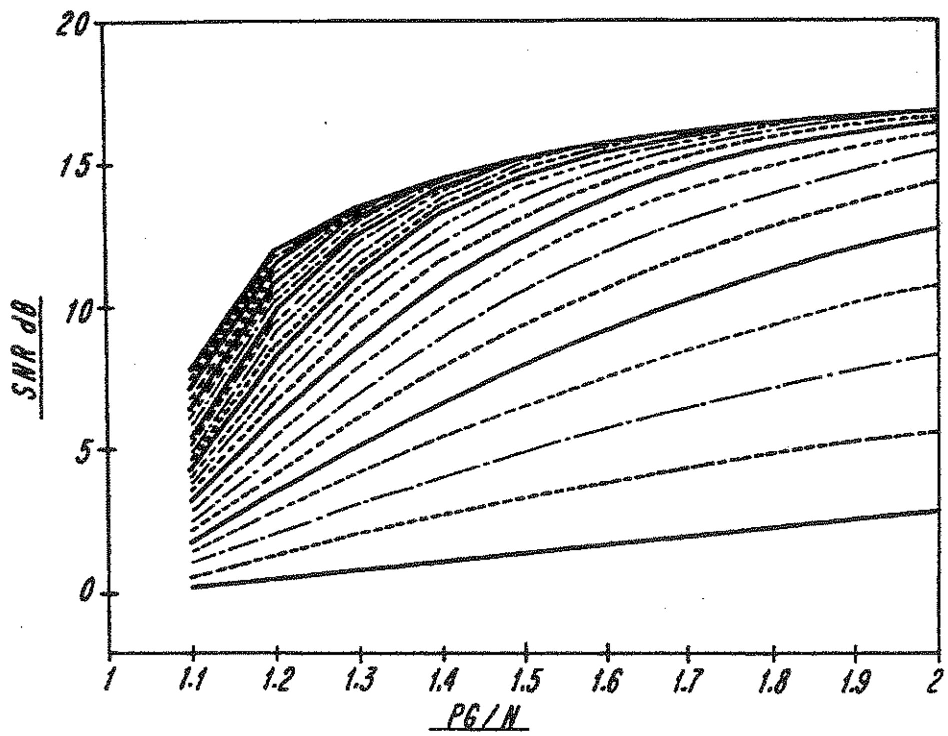

10
8
6
4
2
0
-2
SNR dB
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

Fig. 8



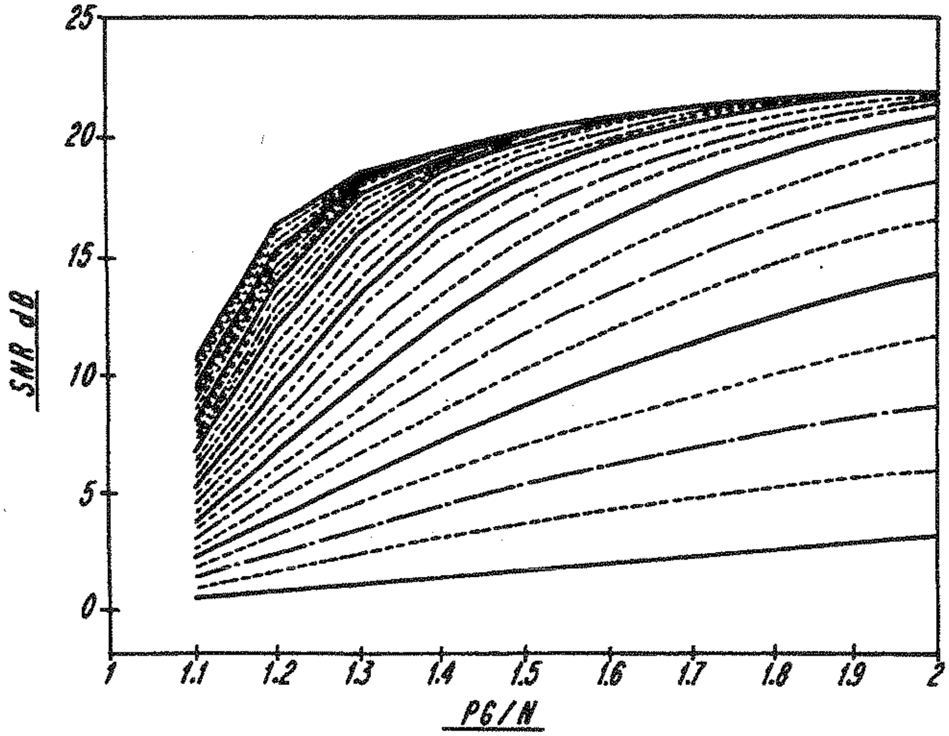
SNR dB
14
12
10
8
6
4
2
0
-2
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

Fig. 9



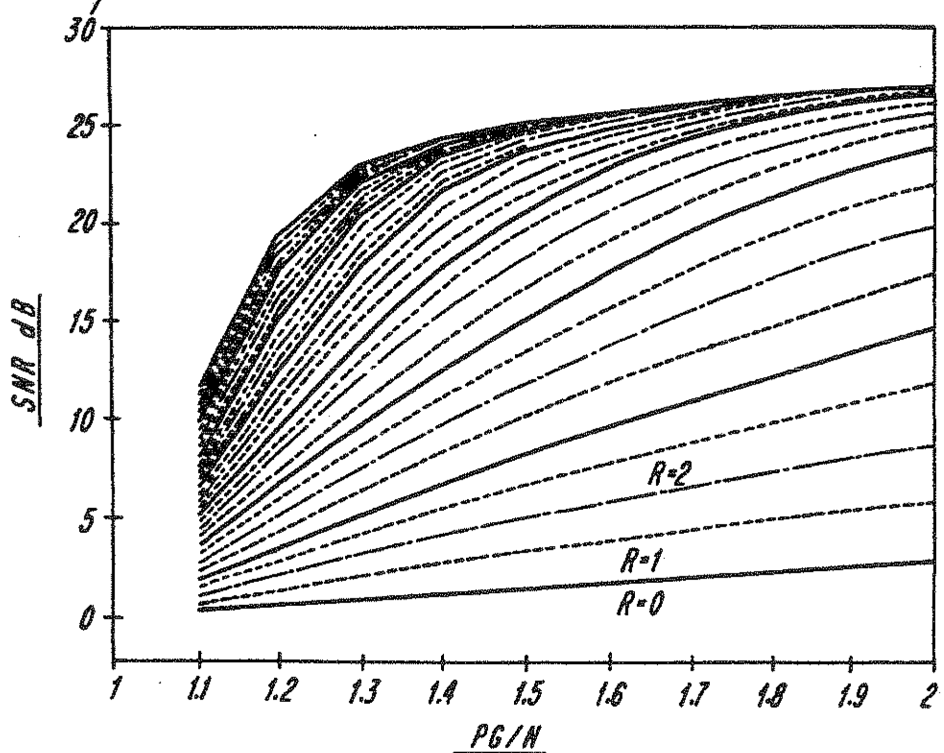
SNR dB
20
15
10
5
0
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

FIG. 10



25
20
15
10
5
0
SNR dB
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

FIG. 11



30
25
20
15
10
5
0
SNR dB
R=2
R=1
R=0
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

SPREAD SPECTRUM CDMA SUBTRACTIVE INTERFERENCE CANCELER AND METHOD

BACKGROUND OF THE INVENTION

This invention relates to spread-spectrum communications, and more particularly to an interference canceler and method for reducing interference in a direct sequence, code division multiple access receiver.

DESCRIPTION OF THE RELEVANT ART

Direct sequence, code division multiple access, spread-spectrum communications systems are capacity limited by interference caused by other simultaneous users. This is compounded if adaptive power control is not used, or is used but is not perfect.

Code division multiple access is interference limited. The more users transmitting simultaneously, the higher the bit error rate (BER). Increased capacity requires forward error correction (FEC) coding, which in turn, increases the data rate and limits capacity.

SUMMARY OF THE INVENTION

A general object of the invention is to reduce noise resulting from N-1 interfering signals in a direct sequence, spread-spectrum code division multiple access receiver.

The present invention, as embodied and broadly described herein, provides a spread-spectrum code division multiple access (CDMA) interference canceler for reducing interference in a spread-spectrum CDMA receiver having N channels. Each of the N channels is spread-spectrum processed by a distinct chip-code signal. The chip-code signal, preferably, is derived from a distinct pseudo-noise (PN) sequence, which may be generated from a distinct chip codeword. The interference canceler partially cancels N-1 interfering CDMA channels, and provides a signal-to-noise ratio (SNR) improvement of approximately N/PG, where PG is the processing gain. Processing gain is the ratio of the chip rate divided by the bit rate. By canceling or reducing interference, the SNR primarily may be due to thermal noise, and residual, interference-produced noise. Thus, the SNR may increase, lowering the BER, which reduces the demand for a FEC encoder/decoder.

The interference canceler, for a particular channel, includes a plurality of despreading means, a plurality of spread-spectrum-processing means, subtracting means, and channel-despreading means. Using a plurality of chip-code signals, the plurality of despreading means despreads the spread-spectrum CDMA signals as a plurality of despread signals, respectively. The plurality of spread-spectrum-processing means uses a timed version of the plurality of chip-code signals, for spread-spectrum processing the plurality of despread signals, respectively, with a chip-code signal corresponding to a respective despread signal. The timed version of a chip-code signal may be generated by delaying the chip-code signal from a chip-code-signal generator. Alternatively, a matched filter may detect a particular PN sequence in the spread-spectrum CDMA signal. A chip-code-signal generator may use the detected signal from the matched filter to trigger a timed version of the chip-code signal.

For recovering a particular CDMA channel using an i^{th} chip-code signal, the subtracting means subtracts from the spread-spectrum CDMA signal, each of the N-1 spread-spectrum-processed-despread signals, thereby generating a subtracted signal. The N-1 spread-spectrum-processed-despread signals do not include the spread-spectrum-processed-despread signal of the i^{th} channel corresponding to the i^{th} chip-code signal. The channel-despreading means despreads the subtracted signal with the i^{th} chip-code signal.

The present invention also includes a method for reducing interference in a spread-spectrum CDMA receiver having N channels. The method comprises the steps of despreading, using a plurality of chip-code signals, the spread-spectrum CDMA signal as a plurality of despread signals, respectively; spread-spectrum processing, using a timed version of the plurality of chip-code signals, the plurality of despread signals, respectively, with a chip-code signal corresponding to a respective despread signal; subtracting from the spread-spectrum CDMA signal, each of the N-1 spread-spectrum-processed-despread signals, with the N-1 spread-spectrum-processed-despread signals not including a spread-spectrum-processed despread signal of the i^{th} channels, thereby generating a subtracted signal; and, despreading the subtracted signal having the i^{th} chip-code signal.

Additional objects and advantages of the invention are set forth in part in the description which follows, and in part are obvious from the description, or may be learned by practice of the invention. The objects and advantages of the invention also may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate preferred embodiments of the invention, and together with the description serve to explain the principles of the invention.

FIG. 1 is a block diagram of the spread-spectrum CDMA interference canceler using correlators;

FIG. 2 is a block diagram of the spread-spectrum CDMA interference canceler for processing multiple channels using correlators;

FIG. 3 is a block diagram of the spread-spectrum CDMA interference canceler using matched filters;

FIG. 4 is a block diagram of the spread-spectrum CDMA interference canceler for processing multiple channels using matched filters;

FIG. 5 is a block diagram of the spread-spectrum CDMA interference canceler having multiple iterations for processing multiple channels;

FIG. 6 illustrates theoretical performance characteristic for $E_b/\eta=6$ dB;

FIG. 7 illustrates theoretical performance characteristic for $E_b/\eta=10$ dB;

FIG. 8 illustrates theoretical performance characteristic for $E_b/\eta=15$ dB;

FIG. 9 illustrates theoretical performance characteristic for $E_b/\eta=20$ dB;

FIG. 10 illustrates theoretical performance characteristic for $E_b/\eta=25$ dB; and

FIG. 11 illustrates theoretical performance characteristic for $E_b/\eta=30$ dB.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference now is made in detail to the present preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings,

wherein like reference numerals indicate like elements throughout the several views.

In the exemplary arrangement shown in FIG. 1, a spread-spectrum code division multiple access (CDMA) interference canceler is provided for reducing interference in a spread-spectrum CDMA receiver having N channels. The present invention also works on a spread-spectrum code division multiplexed (CDM) system. Accordingly, without loss of generality, the term spread-spectrum CDMA signal, as used herein, includes spread-spectrum CDMA signals and spread-spectrum CDM signals. In a personal communications service, the interference canceler may be used at a base station or in a remote unit such as a handset.

FIG. 1 illustrates the interference canceler for the first channel, defined by the first chip-code signal. The interference canceler includes a plurality of despreading means, a plurality of timing means, a plurality of spread-spectrum-processing means, subtracting means, and first channel-despreading means.

Using a plurality of chip-code signals, the plurality of despreading means despreads the received spread-spectrum CDMA signals as a plurality of despread signals, respectively. In FIG. 1 the plurality of despreading means is shown as first despreading means, second despreading means, through N^{th} despreading means. The first despreading means includes a first correlator, which is embodied, by way of example, as a first mixer 51, first chip-code-signal generator 52, and a first integrator 54. The first integrator 54 alternatively may be a first lowpass filter or a first bandpass filter. The first mixer 51 is coupled between the input 41 and the first chip-code-signal generator 52 and the first integrator 54.

The second despreading means includes a second correlator, which is embodied, by way of example, as second mixer 61, second chip-code-signal generator 62 and second integrator 64. The second integrator 64 alternatively may be a second lowpass filter or a second bandpass filter. The second mixer 61, is coupled between the input 41, the second chip-code-signal generator 62, and the second integrator 64.

The N^{th} despreading means is depicted as an N^{th} correlator shown, by way of example, as N^{th} mixer 71, and N^{th} chip-code-signal generator 72, and N^{th} integrator 74. The N^{th} integrator 74 alternatively may be an N^{th} lowpass filter or an N^{th} bandpass filter. The N^{th} mixer 71 is coupled between the input 41, the N^{th} chip-code-signal generator 72 and the N^{th} integrator 74.

As is well known in the art, the first through N^{th} despreading means may be embodied as any device which can despread a channel in a spread-spectrum signal.

The plurality of timing means may be embodied as a plurality of delay devices 53, 63, 73. A first delay device 53 has a delay time T, which is approximately the same as the integration time T_b of first integrator 54, or time constant of the first lowpass filter or first bandpass filter. A second delay device 63 has a time delay T, which is approximately the same as the integration time T_b of second integrator 64, or time constant of the second lowpass filter or second bandpass filter. Similarly, the N^{th} delay device 73 has a time delay T, which is approximately the same as the integration time T_b of N^{th} integrator 74, or time constant of the N^{th} lowpass filter or N^{th} bandpass filter. Typically, the integration times of the first integrator 54, second integrator 64 through N^{th} integrator 74 are the same. If lowpass filters are used, then typically the time constants of the first lowpass filter, second lowpass filter through N^{th} lowpass filter are the same. If bandpass filters are used, then the time constants of the first bandpass filter, second bandpass filter through N^{th} bandpass filter are the same.

The plurality of spread-spectrum-processing means regenerates each of the plurality of despread signals as a plurality of spread-spectrum signals. The plurality of spread-spectrum-processing means uses a timed version, i.e. delayed version, of the plurality of chip-code signals, for spread-spectrum processing the plurality of despread signals, respectively, with a chip-code signal corresponding to a respective despread signal. The plurality of spread-spectrum-processing means is shown, by way of example, as a first processing mixer 55, a second processing mixer 65, through an N^{th} processing mixer 75. The first processing mixer 55 is coupled to the first integrator 54, and through a first delay device 53 to the first chip-code-signal generator 52. The second processing mixer 65 is coupled to the second integrator 64, and through the second delay device 63 to the second chip-code-signal generator 62. The N^{th} processing mixer 75 is coupled to the N^{th} integrator 74 through the delay device 73 to the N^{th} chip-code-signal generator 72.

For reducing interference to a channel using an i^{th} chip-code signal of the spread-spectrum CDMA signal, the subtracting means subtracts, from the spread-spectrum CDMA signal, each of the N-1 spread-spectrum-processed-despread signals not corresponding to the i^{th} channel. The subtracting means thereby generates a subtracted signal. The subtracting means is shown as a first subtractor 150. The first subtractor 150 is shown coupled to the output of the second processing mixer 65, through the N^{th} processing mixer 75. Additionally, the first subtractor 150 is coupled through a main delay device 48 to the input 41.

The i^{th} channel-despreading means despreads the subtracted signal with the i^{th} chip-code signal as the i^{th} channel. The first channel-despreading means is shown as a first channel mixer 147. The first channel mixer 147 is coupled to the first delay device 53, and to the first subtractor 150. The first channel integrator 146 is coupled to the first channel mixer 147.

The first chip-code-signal generator 52, the second chip-code-signal generator 62, through the N^{th} chip-code-signal generator 72 generate a first chip-code signal, a second chip-code signal, through a N^{th} chip-code signal, respectively. The term "chip-code signal" is used herein to mean the spreading signal of a spread-spectrum signal, as is well known in the art. Typically the chip-code signal is generated from a pseudo-random (PN) sequence. The first chip-code signal, the second chip code signal, through the N^{th} chip-code signal might be generated from a first PN sequence, a second PN sequence, through a N^{th} PN sequence, respectively. The first PN sequence is defined by or generated from a first chip codeword, the second PN sequence is defined by or generated from a second chip codeword, through the N^{th} PN sequence is defined by or generated from a N^{th} chip-codeword. Each of the first chip codeword, second chip codeword through N^{th} chip codeword is distinct, i.e. different from one another. In general, a chip codeword can be the actual sequence of a PN sequence, or used to define settings for generating the PN sequence. The settings might be the delay taps of shift registers, for example.

A first channel of a received spread-spectrum CDMA signal at input 41 is despread by first mixer 51 as a first despread signal, using the first chip-code signal generated by first chip-code-signal generator 52. The first despread signal from the first mixer 51 is filtered through first integrator 54. First integrator 54 integrates for a time T_b, the time duration of a symbol such as a bit. At the same time, the first chip-code signal is delayed by time T by delay device 53. The delay time T is approximately equal to the integration time T_b plus system or component delays. Systems or component delays are usually small, compared to integration time T_b.

The delayed version of the first chip-code signal is processed with the first despread signal from the output of the first integrator 54 using the first spreading mixer 55. The output of the first spreading mixer 55 is fed to subtractors other than first subtractor 150 for processing the second through N^{th} channels of the spread-spectrum CDMA signal.

For reducing interference to the first channel of the spread-spectrum CDMA signal, the received spread-spectrum CDMA signal is processed by the second through N^{th} despreaders as follows. The second channel of the spread-spectrum CDMA signal is despread by the second despreading means. At the second mixer 61, a second chip-code signal, generated by the second chip-code-signal generator 62, despreads the second channel of the spread-spectrum CDMA signal. The despread second channel is filtered through second integrator 64. The output of the second integrator 64 is the second despread signal. The second despread signal is spread-spectrum processed by second processing mixer 65 by a delayed version of the second chip-code signal. The second chip-code signal is delayed through delay device 63. The delay device 63 delays the second chip-code signal by time T. The second channel mixer 65 spread-spectrum processes a timed version, i.e. delayed version, of the second chip-code signal with the filtered version of the second spread-spectrum channel from second integrator 64. The term "spread-spectrum process" as used herein includes any method for generating a spread-spectrum signal by mixing or modulating a signal with a chip-code signal. Spread-spectrum processing may be done by product devices, EXCLUSIVE-OR gates, matched filters, or any other device or circuit as is well known in the art.

Similarly, the N^{th} channel of the spread-spectrum CDMA signal is despread by the N^{th} despreading means. Accordingly, the received spread-spectrum CDMA signal has the N^{th} channel despread by N^{th} mixer 71, by mixing the spread-spectrum CDMA signal with the N^{th} chip-code signal from N^{th} chip-code-signal generator 72. The output of the N^{th} mixer 71 is filtered by N^{th} integrator 74. The output of the N^{th} integrator 74, which is the N^{th} despread signal, is a despread and filtered version of the N^{th} channel of the spread-spectrum CDMA signal. The N^{th} despread signal is spread-spectrum processed by a delayed version of the N^{th} chip-code signal. The N^{th} chip-code signal is delayed through N^{th} delay device 73. The N^{th} processing mixer 75 spread-spectrum processes the timed version, i.e. a delayed version, of the N^{th} chip-code signal with the N^{th} despread signal.

At the first subtractor 150, each of the outputs of the second processing mixer 65 through the N^{th} processing mixer 75 is subtracted from a timed version, i.e. a delayed version, of the spread-spectrum CDMA signal from input 41. The delay of the spread-spectrum CDMA signal is timed through the first main delay device 48. Typically, the delay of the first main delay device 48 is time T, which is approximately equal to the integration time of the first integrator 54 through N^{th} integrator 74.

At the output of the first subtractor 150, is generated a first subtracted signal. The first subtracted signal, for the first channel of the spread-spectrum CDMA signal, is defined herein to be the outputs from the second processing mixer 65 through N^{th} processing mixer 75, subtracted from the delayed version of the spread-spectrum CDMA signal. The second subtracted signal through N^{th} subtracted signal are similarly defined.

The delayed version of the first chip-code signal from the output of first delay device 53 is used to despread the output of the first subtractor 150. Accordingly, the first subtracted signal is despread by the first chip-code signal by first channel mixer 147. The output of the first channel mixer 147 is filtered by first channel integrator 147. This produces an output estimate d_1 of the first channel of the spread-spectrum CDMA signal.

As illustratively shown in FIG. 2, a plurality of subtractors 150, 250, 350, 450 can be coupled appropriately to the input 41 and to a first spreading mixer 55, second spreading mixer 65, third spreading mixer, through an N^{th} spreading mixer 75 of FIG. 1. The plurality of subtractors 150, 250, 350, 450 also are coupled to the main delay device 48 from the input 41. This arrangement can generate a first subtracted signal from the first subtractor 150, a second subtracted signal from the second subtractor 250, a third subtracted signal from the third subtractor 350, through an N^{th} subtracted signal from an N^{th} subtractor 450.

The outputs of the first subtractor 150, second subtractor 250, third subtractor 350, through the N^{th} subtractor 450 are each coupled to a respective first channel mixer 147, second channel mixer 247, third channel mixer 347, through N^{th} channel mixer 447. Each of the channel mixers is coupled to a delayed version of the first chip-code signal, $g_1(t-T)$, second chip-code signal, $g_2(t-T)$, third chip-code signal, $g_3(t-T)$, through N^{th} chip-code signal, $g_N(t-T)$. The outputs of each of the respective first channel mixer 147, second channel mixer 247, third channel mixer 347, through N^{th} channel mixer 447 are coupled to a first channel integrator 146, second channel integrator 246, third channel integrator 346 through N^{th} channel integrator 446, respectively. At the output of each of the channel integrators is produced an estimate of the respective first channel d_1, second channel d_2, third channel d_3, through N^{th} channel d_N.

Referring to FIG. 1, use of the present invention is illustrated for the first channel of the spread-spectrum CDMA signal, with the understanding that the second through N^{th} CDMA channels work similarly. A received spread-spectrum CDMA signal at input 41 is delayed by delay device 48 and fed to the first subtractor 150. The spread-spectrum CDMA signal has the second channel through N^{th} channel despread by second mixer 61 using the second chip-code signal, through the N^{th} mixer 71 using the N^{th} chip-code signal. The respective second chip-code signal through the N^{th} chip-code signal are generated by the second chip-code-signal generator 62 through the N^{th} chip-code-signal generator 72. The second channel through N^{th} channel are despread and filtered through the second integrator 64 through the N^{th} integrator 74, respectively. The despreading removes, partially or totally, the non-

despread channels at the outputs of each of the second integrator 64 through N^{th} integrator 74.

In a preferred embodiment, each of the chip-code signal used for the first chip-code-signal generator 52, second chip-code-signal generator 62 through the N^{th} chip-code-signal generator 72, are orthogonal to each other. Use of chip-code signals having orthogonality however, is not required for operation of the present invention. When using orthogonal chip-code signals, the despread signals have the respective channel plus noise at the output of each of the integrators. With orthogonal chip-code signals, theoretically the mixers remove channels orthogonal to the despread channel. The respective channel is spread-spectrum processed by the respective processing mixer.

At the output of the second processing mixer 65 through the N^{th} processing mixer 75 is a respread version of the second channel through the N^{th} channel, plus noise components contained therein. Each of the second channel through N^{th} channel is then subtracted from the received spread-spectrum CDMA signal by the first subtractor 150. The first subtractor 150 produces the first subtracted signal. The first subtracted signal is despread by a delayed version of the first chip-code signal by first channel mixer 147, and filtered by first channel filter 146. Accordingly, prior to despreading the first channel of the spread-spectrum CDMA signal, the second through N^{th} channels plus noise components aligned with these channels are subtracted from the received spread-spectrum CDMA signal. As illustratively shown in FIG. 3, an alternative embodiment of the spread-spectrum CDMA interference canceler includes a plurality of first despreading means, a plurality of spread-spectrum-processing means, subtracting means, and second despreading means. In FIG. 3, the plurality of despreading means is shown as first despreading means, second despreading means through N^{th} despreading means. The first despreading means is embodied as a first matched filter 154. The first matched filter 154 has an impulse response matched to the first chip-code signal, which is used to spread-spectrum process and define the first channel of the spread-spectrum CDMA signal. The first matched filter 154 is coupled to the input 41.

The second despreading means is shown as second matched filter 164. The second matched filter 164 has an impulse response matched to the second chip-code signal, which is used to spread-spectrum process and define the second channel of the spread-spectrum CDMA signal. The second matched filter 164 is coupled to the input 41.

The N^{th} despreading means is shown an N^{th} matched filter 174. The N^{th} matched filter has an impulse response matched to the N^{th} chip-code signal, which is used to spread-spectrum process and define the N^{th} channel of the spread-spectrum CDMA signal. The N^{th} matched filter is coupled to the input 41.

The term matched filter, as used herein, includes any type of matched filter that can be matched to a chip-code signal. The matched filter may be a digital matched filter or analog matched filter. A surface acoustic wave (SAW) device may be used at a radio frequency (RF) or intermediate frequency (IF). Digital signal processors and application specific integrated circuits (ASIC) having matched filters may be used at RF, IF or baseband frequency.

In FIG. 3, the plurality of spread-spectrum-processing means is shown as the first processing mixer 55, the second processing mixer 65, through the N^{th} processing mixer 75. The first processing mixer 55 may be coupled through a first adjustment device 97 to the first chip-code-signal generator 52. The second processing mixer 65 may be coupled through the second adjustment device 98 to the second chip-code-signal generator 62. The N^{th} processing mixer 75 may be coupled through the N^{th} adjustment device 73 to the N^{th} chip-code-signal generator 72. The first adjustment device 97, second adjustment device 98 through N^{th} adjustment device 99 are optional, and are used as an adjustment for aligning the first chip-code signal, second chip-code signal through N^{th} chip-code signal with the first despread signal, second despread signal through N^{th} despread signal, outputted from the first matched filter 154, second matched filter 164 through N^{th} matched filter 174, respectively.

The subtracting means is shown as the first subtractor 150. The first subtractor 150 is coupled to the output of the second processing mixer 65, through the N^{th} processing mixer 75. Additionally, the first subtractor 150 is coupled through the main delay device 48 to the input 41.

The first channel-despreading means is shown as a first channel-matched filter 126. The first channel-matched filter 126 is coupled to the first subtractor 150. The first channel-matched filter 126 has an impulse response matched to the first chip-code signal.

A first channel of a received spread-spectrum CDMA signal, at input 41, is despread by first matched filter 154. The first matched filter 154 has an impulse response matched to the first chip-code signal. The first chip-code signal defines the first channel of the spread-spectrum CDMA signal, and is used by the first chip-code-signal generator 52. The first chip-code signal may be delayed by adjustment time τ by adjustment device 97. The output of the first matched filter 154 is spread-spectrum processed by the first processing mixer 55 with the first chip-code signal. The output of the first processing mixer 55 is fed to subtractors other than the first subtractor 150 for processing the second channel through N^{th} channel of the spread-spectrum CDMA signals.

For reducing interference to the first spread-spectrum channel, the received spread-spectrum CDMA signal is processed by the second despreading means through N^{th} despreading means as follows. The second matched filter 164 has an impulse response matched to the second chip-code signal. The second chip-code signal defines the second channel of the spread-spectrum CDMA signal, and is used by the second chip-code-signal generator 62. The second matched filter 164 despreads the second channel of the spread-spectrum CDMA signal. The output of the second matched filter 164 is the second despread signal. The second despread signal triggers second chip-code-signal generator 62. The second despread signal also is spread-spectrum processed by second processing mixer 65 by a timed version of the second chip-code signal. The timing of the second chip-code signal triggers the second despread signal from the second matched filter 164.

Similarly, the N^{th} channel of the spread-spectrum CDMA signal is despread by the N^{th} despreading means. Accordingly, the received spread-spectrum CDMA signal has the N^{th} channel despread by N^{th} matched filter 174. The output of the N^{th} matched filter 174 is the N^{th} despread signal, i.e. a despread and filtered version of the N^{th} channel of the spread-spectrum

CDMA signal. The N^{th} despread signal is spread-spectrum processed by a timed version of the N^{th} chip-code signal. The timing of the N^{th} chip-code signal is triggered by the N^{th} despread signal from the N^{th} matched filter **174**. The N^{th} processing mixer **75** spread-spectrum processes the timed version of the N^{th} chip-code signal with the N^{th} despread signal.

At the first subtractor **150**, each of the outputs of the second processing mixer **65** through the N^{th} processing mixer **75** are subtracted from a delayed version of the spread-spectrum CDMA signal from input **41**. The delay of the spread-spectrum CDMA signal is timed through delay device **48**. The time of delay device **48** is set to align the second through N^{th} spread-spectrum-processed-despread signals for subtraction from the spread-spectrum CDMA signal. This generates at the output of the first subtractor **150**, a first subtracted signal. The subtracted signal is despread by the first channel-matched filter **126**. This produces an output estimate d_1 of the first channel of the spread-spectrum CDMA signal.

As illustrated in FIG. **4**, a plurality of subtractors **150**, **250**, **350**, **450** can be coupled appropriately to the output from a first processing mixer, second processing mixer, third processing mixer, through a N^{th} processing mixer, and to a main delay device from the input. A first subtracted signal is outputted from the first subtractor **150**, a second subtracted signal is outputted from the second subtractor **250**, a third subtracted signal is outputted from the third subtractor **350**, through an N^{th} subtractor signal is outputted from an N^{th} subtractor **450**.

The output of the first subtractor **150**, second subtractor **250**, third subtractor **350**, through the N^{th} subtractor **450** are each coupled to a respective first channel-matched filter **126**, second channel-matched filter **226**, third channel-matched filter **326**, through N^{th} channel-matched filter **426**. The first channel-matched filter **126**, second channel-matched filter **226**, third channel-matched filter **326** through N^{th} channel-matched filter **426** have an impulse response matched the first chip-code signal, second chip-code signal, third chip-code signal, through N^{th} chip-code signal, defining the first channel, second channel, third channel through N^{th} channel, respectively, of the spread-spectrum CDMA signal. At each of the outputs of the respective first channel-matched filter **126**, second channel-matched filter **226**, third channel-matched filter **326**, through N^{th} channel-matched filter **426**, is produced an estimate of the respective first channel d_1, second channel d_2, third channel d_3, through N^{th} channel d_n.

In use, the present invention is illustrated for the first channel of the spread-spectrum CDMA signal, with the understanding that the second channel through N^{th} channel work similarly. A received spread-spectrum CDMA signal at input **41** is delayed by delay device **48** and fed to subtractor **150**. The same spread-spectrum CDMA signal has the second through N^{th} channel despread by the second matched filter **164** through the N^{th} matched filter **174**. This despreading removes the other CDMA channels from the respective despread channel. In a preferred embodiment, each of the chip-code signals used for the first channel, second channel, through the N^{th} channel, is orthogonal to the other chip-code signals. At the output of the first matched filter **154**, second matched filter **164** through N^{th} matched filter **174**, are the first despread signal, second despread signal through N^{th} despread signal, plus noise.

The respective channel is spread-spectrum processed by the processing mixers. Accordingly, at the output of the second processing mixer **65** through the N^{th} processing mixer **75** is a spread version of the second despread signal through the N^{th} despread signal, plus noise components contained therein. Each of the spread-spectrum-processed-despread signals, is then subtracted from the received spread-spectrum CDMA signal by the first subtractor **150**. This produces the first subtracted signal.

The first subtracted signal is despread by first channel-matched filter **126**. Accordingly, prior to despreading the first channel of the spread-spectrum CDMA signal, the second channel through N^{th} channel plus noise components aligned with these channels, are subtracted from the received spread-spectrum CDMA signal.

As is well known in the art, correlators and matched filters may be interchanged to accomplish the same function. FIGS. **1** and **3** show alternate embodiments using correlators or matched filters. The arrangements may be varied. For example, the plurality of despreading means may be embodied as a plurality of matched filters, while the channel despreading means may be embodied as a correlator. Alternatively, the plurality of despreading means may be a combination of matched filters and correlators. Also, the spread-spectrum-processing means my be embodied as a matched filter or SAW, or as EXCLUSIVE-OR gates or other devices for mixing a despread signal with a chip-code signal. As is well known in the art, any spread-spectrum despreader or demodulator may despread the spread-spectrum CDMA signal. The particular circuits shown in FIGS. **1–4** illustrate the invention by way of example.

The concepts taught in FIGS. **1–4** may be repeated, as shown in FIG. **5**. FIG. **5** illustrates a first plurality of interference cancelers **511**, **512**, **513**, a second plurality of interference cancelers **521**, **522**, **523**, through an N^{th} plurality of interference cancelers **531**, **532**, **533**. Each plurality of interference cancelers includes appropriate elements as already disclosed, and referring to FIGS. **1–4**. The input is delayed through a delay device in each interference canceler.

The received spread-spectrum CDMA signal has interference canceled initially by the first plurality of interference cancelers **511**, **512**, **513**, thereby producing a first set of estimates, i.e. a first estimate d_{11}, a second estimate d_{12}, through an N^{th} estimate d_{1N}, of the first channel, second channel through the N^{th} channel, of the spread-spectrum CDMA signal. The first set of estimates can have interference canceled by the second plurality of interference cancelers **521**, **522**, **523**. The first set of estimates $d_{11}, d_{12}, \ldots, d_{1N}$, of the first channel, second channel through N^{th} channel, are input to the second plurality of interference cancelers, interference canceler **521**, interference canceler **522** through N^{th} interference canceler **523** of the second plurality of interference cancelers. The second plurality of interference cancelers thereby produce a second set of estimates, i.e. $d_{21}, d_{22}, \ldots, d_{2N}$, of the first channel, second channel, through N^{th} channel. Similarly, the second set estimates can pass through a third plurality of interference cancelers, and ultimately through an M^{th} set of interference cancelers **531**, **532**, **533**, respectively.

The present invention also includes a method for reducing interference in a spread-spectrum CDMA receiver having N chip-code channels. Each of the N channels is identified by a distinct chip-code signal. The

method comprises the steps of despreading, using a plurality of chip-code signals, the spread-spectrum CDMA signal as a plurality of despread signals, respectively. Using a timed version of the plurality of chip-code signals, the plurality of despread signals are spread-spectrum processed with a chip-code signal corresponding to a respective despread signal. Each of the N-1 spread-spectrum-processed-despread signals, is subtracted from the spread-spectrum CDMA signal, with the N-1 spread-spectrum-processed-despread signals not including a spread-spectrum-processed signal of the i^{th} despread signal, thereby generating a subtracted signal. The subtracted signal is despread to generate the i^{th} channel.

The probability of error P_e for direct sequence, spread-spectrum CDMA system is:

$$P_e = \tfrac{1}{2}\mathrm{erfc}(\alpha SNR)^{\frac{1}{2}}$$

where erfc is complementary error function, SNR is signal-to-noise ratio, and $1 \leqq \alpha \leqq 2$. The value of e depends on how a particular interference canceler system is designed.

The SNR after interference cancellation and method is given by:

$$SNR = \frac{(PG/N)^{R+1}}{1 + (PG/N)^{R+1} \frac{1}{E_b/\eta} \frac{1-(N/PG)^{R+1}}{1-N/PG}}$$

where N is the number of channels, PG is the processing gain, R is the number of repetitions of the interference canceler, E_b is energy per information bit and η is noise power spectral density.

FIG. 6 illustrates theoretical performance characteristic, of the interference canceler and method for when $E_b/\eta = 6$ dB. The performance characteristic is illustrated for SNR out of the interference canceler, versus PG/N. The lowest curve, for $R=0$, is the performance without the interference canceler. The curves, for $R=1$ and $R=2$, illustrates improved performance for using one and two iterations of the interference canceler as shown in FIG. 5. As $PG/N \rightarrow 1$, there is insufficient SNR to operate. If $PG > N$, then the output SNR from the interference canceler approaches E_b/η. Further, if $(N/PG)^{R+1} << 1$, then

$$SNR \rightarrow (E_b/\eta)(1-N/PG).$$

FIG. 7 illustrates the performance characteristic for when $E_b/\eta = 10$ dB. FIG. 7 illustrates that three iterations of the interference canceler can yield a 4 dB improvement with $PG/N=2$.

FIG. 8 illustrates the performance characteristic for when $E_b/\eta = 15$ dB. With this bit energy to noise ratio, two iterations of the interference canceler can yield 6 dB improvement for $PG/N=2$.

FIG. 9 illustrates the performance characteristic for when $E_b/\eta = 20$ dB. With this bit energy to noise ratio, two iterations of the interference canceler can yield 6 dB improvement for $PG/N=2$. Similarly, FIGS. 10 and 11 shows that one iteration of the interference canceler can yield more than 10 dB improvement for $PG/N=2$.

It will be apparent to those skilled in the art that various modifications can be made to the spread-spectrum CDMA interference canceler and method of the instant invention without departing from the scope or spirit of the invention, and it is intended that the present invention cover modifications and variations of the spread-spectrum CDMA interference canceler and method provided they come within the scope of the appended claims and their equivalents.

We claim:

1. A spread-spectrum code division multiple access (CDMA) interference canceler for reducing interference in a spread-spectrum CDMA receiver having N channels, with each of the N channels identified by a distinct chip-code signal, comprising:

a plurality of means for generating a plurality of chip-code signals;

a plurality of despreading means, with each of said despreading means responsive to the respective distinct chip-code signal identifying a corresponding one of the N channels, for simultaneously despreading a plurality of spread-spectrum channels of a spread-spectrum CDMA signal as a plurality of despread signals, respectively;

a plurality of means for timing the plurality of chip-code signals thereby generating a timed version of the plurality of chip-code signals, respectively;

a plurality of means, responsive to the timed version of the plurality of chip-code-signals, for simultaneously spread-spectrum processing the plurality of despread signals, respectively, with a chip-code-signal corresponding to a respective despread signal;

means, for an i^{th} chip-code signal, for subtracting from the spread-spectrum CDMA signal, simultaneously, each of the N-1 spread-spectrum-processed-despread signals, with the N-1 spread-spectrum-processed-despread signals not including a spread-spectrum processed-despread signal of the i^{th} despread signal, thereby generating a subtracted signal; and

channel means for despreading the subtracted signal with the i^{th} chip-code signal as an i^{th} channel.

2. The spread-spectrum CDMA interference canceler as set forth in claim 1 wherein each of said plurality of despreading means includes:

a filter;

a chip-code generator for generating a chip-code signal from a respective chip codeword; and

a mixer coupled between said filter and said chip-code generator.

3. The spread-spectrum CDMA interference canceler as set forth in claim 1 wherein each of said plurality of despreading means includes a matched filter having an impulse response matched to a respective chip codeword.

4. The spread-spectrum CDMA interference canceler as set forth in claim 1 wherein said channel-despreading means includes:

a filter;

a chip-code generator for generating a chip-code signal from a chip codeword corresponding to the i^{th} channel; and a mixer coupled between said filter and said chip-code generator.

5. The spread-spectrum CDMA interference canceler as set forth in claim 2 wherein said channel-despreading means includes:

a filter;

a chip-code generator for generating a chip-code signal from a chip codeword corresponding to the i^{th} channel; and

a mixer coupled between said filter and said chip-code generator.

6. The spread-spectrum CDMA interference canceler as set forth in claim 3 wherein said channel-despreading means includes:

a filter;

a chip-code generator for generating a chip-code signal from a chip codeword corresponding to the i^{th} channel; and

a mixer coupled between said filter and said chip-code generator.

7. The spread-spectrum CDMA interference canceler as set forth in claim 3 wherein said channel-despreading means includes a matched filter having an impulse response matched to a chip codeword corresponding to the i^{th} channel.

8. The spread-spectrum CDMA interference canceler as set forth in claim 1 wherein each of said despreading means includes a digital signal processor with digital matched filter having an impulse response matched to a respective chip codeword.

9. The spread-spectrum CDMA interference canceler as set forth in claim 8 wherein said channel-despreading means includes a matched filter having an impulse response matched to a chip codeword corresponding to the i^{th} channel.

10. The spread-spectrum CDMA interference canceler as set forth in claim 1 wherein said channel-despreading means includes a digital signal processor with digital matched filter having an impulse response matched to a chip codeword corresponding to the i^{th} channel.

11. The spread-spectrum CDMA interference canceler as set forth in claim 8 wherein said channel-despreading means includes a surface acoustic wave (SAW) device having an impulse response matched to a chip codeword corresponding to the i^{th} channel.

12. The spread-spectrum CDMA interference canceler as set forth in claim 1 wherein each of said plurality of despreading means includes a surface acoustic wave (SAW) device having an impulse response matched to a chip codeword corresponding to the i^{th} channel.

13. The spread-spectrum CDMA interference canceler as set forth in claim 12 wherein said channel-despreading means includes a matched filter having an impulse response matched to a chip codeword corresponding to the i^{th} channel.

14. The spread-spectrum CDMA interference canceler as set forth in claim 12 wherein said channel-despreading means includes a chip-code generator for generating a chip-code signal from a digital matched filter having an impulse response matched to a chip codeword corresponding to the i^{th} channel.

15. The spread-spectrum CDMA interference canceler as set forth in claim 12 wherein said channel-despreading means includes a surface acoustic wave (SAW) device having an impulse response matched to a chip codeword corresponding to the i^{th} channel.

16. A spread-spectrum code division multiple access (CDMA) interference canceler for reducing interference in a spread-spectrum CDMA receiver having N channels, with each of the N channels identified by a distinct chip-code signal, comprising:

a plurality of chip-code-signal generators for generating, simultaneously, a plurality of chip-code signals;

a plurality of correlators, responsive to a plurality of distinct chip-code-signals, for simultaneously despreading a plurality of spread-spectrum channels of a spread-spectrum CDMA signal as a plurality of despread signals, respectively;

a plurality of delay devices coupled to said plurality of chip-code-signal generators for delaying the plurality of chip-code signals as a timed plurality of chip-code signals, respectively;

a plurality of mixers, responsive to the timed plurality of chip-code signals, for spread-spectrum processing, simultaneously, the plurality of despread signals, respectively, with a chip-code-signal corresponding to a respective despread signal;

a subtractor, for an i^{th} chip-code signal, for subtracting from the spread-spectrum CDMA signal, simultaneously, each of the N-1 spread-spectrum-processed-despread signals, with the N-1 spread-spectrum-processed-despread signals not including a spread-spectrum processed despread signal of the i^{th} despread signal, thereby generating a subtracted signal; and

a channel correlator for despreading the subtracted signal with the i^{th} chip-code signal as an i^{th} channel.

17. A spread-spectrum code division multiple access (CDMA) interference canceler for reducing interference in a spread-spectrum CDMA receiver having N chip-code channels, with each of the N channels identified by a distinct chip-code signal, comprising:

a plurality of matched filters, responsive to a plurality of distinct chip-code signals, for simultaneously despreading a plurality of spread-spectrum channels of a spread-spectrum CDMA signal as a plurality of despread signals, respectively;

a plurality of chip-code-signal generators, responsive to a plurality of despread signals from the plurality of matched filters, for generating a timed plurality of chip-code signals, respectively;

a plurality of mixers, responsive to the plurality of despread signals from the plurality of matched filters and the timed plurality of chip-code signals from the plurality of chip-code-signal generators, respectively, for spread-spectrum processing, simultaneously, the plurality of despread signals, respectively, with a timed chip-code signal corresponding to a respective despread signal;

a subtractor, for an i^{th} chip-code signal, for subtracting from the spread-spectrum CDMA signal, simultaneously, each of the N-1 spread-spectrum-processed-despread signals, with the N-1 spread-spectrum-processed-despread signals not including a spread-spectrum processed despread signal of the i^{th} despread signal, thereby generating a subtracted signal; and

a channel matched filter for despreading the subtracted signal with the i^{th} chip-code-signal as an i^{th} channel.

18. A method for reducing interference in a spread-spectrum code division multiple access (CDMA) receiver having N channels, with each of the N channels identified by a distinct chip-code signal, comprising the steps of:

despreading a spread-spectrum CDMA signal as a plurality of despread signals, respectively;

spread-spectrum processing, simultaneously, using a timed version of the plurality of chip-code-signals, the plurality of despread signals, respectively, with a chip-code signal corresponding to a respective despread signal;

subtracting from the spread-spectrum CDMA signal, simultaneously, each of the N-1 spread-spectrum-

processed-despread signals, with the N-1 spread-spectrum-processed-despread signals not including a spread-spectrum processed despread signal of the i^{th} despread signal, thereby generating a subtracted signal; and

despreading the subtracted signal with the i^{th} chip-code signal as an i^{th} channel.

19. The method as set forth in claim 18 wherein the first step of despreading includes the step of correlating the spread-spectrum CDMA signal as a plurality of despread signals.

20. The method as set forth in claim 18 wherein the first step of despreading includes the step of matched filtering the spread-spectrum CDMA signal as a plurality of despread signals.

21. A method for reducing interference in a spread-spectrum code division multiple access (CDMA) receiver having N channels, with each of the N channels identified by a distinct chip-code signal, using a first plurality of interference cancelers, comprising the steps, within each of said plurality of interference cancelers, of:

a. despreading, simultaneously, a plurality of spread-spectrum channels of a spread-spectrum CDMA signal as a plurality of despread signals, respectively;

b. spread-spectrum processing, simultaneously, using a timed version of the plurality of chip-code-signals, the plurality of despread signals, respectively, with a chip-code signal corresponding to a respective despread signal;

c. subtracting from the spread-spectrum CDMA signal, each of the N-1 spread-spectrum-processed-despread signals, with the N-1 spread-spectrum-processed-despread signals not including a spread-spectrum processed despread signal of the i^{th} despread signal, thereby generating a subtracted signal;

d. despreading the subtracted signal with the i^{th} chip-code signal as an i^{th} channel, producing a first set of estimates of the N channels;

e. repeating steps a through d, using a second plurality of interference cancelers, producing a second set of estimates of the N channels; and

f. repeating steps a through d, using an M^{th} plurality of interference cancelers, producing an M^{th} set of estimates of the N channels.

22. A spread-spectrum code division multiple access (CDMA) interference canceler for reducing interference in a spread-spectrum CDMA receiver having N channels, with each of the N channels identified by a distinct chip-code signal, comprising:

a plurality of chip-code-signal generators for generating, simultaneously, a plurality of chip-code signals;

a plurality of correlators, responsive to a plurality of distinct chip-code-signals, for simultaneously despreading a plurality of spread-spectrum channels of a spread-spectrum CDMA signal as a plurality of despread signals, respectively;

a plurality of delay devices coupled to said plurality of chip-code-signal generators for delaying the plurality of chip-code signals as a timed plurality of chip-code signals, respectively;

a plurality of mixers, responsive to the timed plurality of chip-code signals, for spread-spectrum processing, simultaneously, the plurality of despread signals, respectively, with a chip-code-signal corresponding to a respective despread signal, producing N spread-spectrum-processed-despread signals;

a plurality of subtractors, each of said plurality of subtractors for subtracting from the spread-spectrum CDMA signal all but a particular one of the N spread-spectrum-processed-despread signals, with the particular one of the N spread-spectrum-processed-despread signals being different for each of said plurality of subtractors, thereby generating a plurality of subtracted signals; and

a plurality of channel correlators for despreading the plurality of subtracted signals with a particular one of the plurality of chip-code signals, respectively, as a plurality of channels.

23. A spread-spectrum code division multiple access (CDMA) interference canceler for reducing interference in a spread-spectrum CDMA receiver having N channels, with each of the N channels identified by a distinct chip-code signal, comprising:

a plurality of chip-code-signal generators for generating, simultaneously, a plurality of chip-code signals;

a plurality of correlators, responsive to a plurality of distinct chip-code-signals, for simultaneously despreading a plurality of spread-spectrum channels of a spread-spectrum CDMA signal as a plurality of despread signals, respectively;

a plurality of delay devices coupled to said plurality of chip-code-signal generators for delaying the plurality of chip-code signals as a timed plurality of chip-code signals, respectively;

a plurality of mixers, responsive to the timed plurality of chip-code signals, for spread-spectrum processing, simultaneously, the plurality of despread signals, respectively, with a chip-code-signal corresponding to a respective despread signal, producing N spread-spectrum-processed-despread signals;

a first subtractor, for subtracting from the spread-spectrum CDMA signal, all but a first one of the N spread-spectrum-processed-despread signals, thereby generating a first subtracted signal;

a second subtractor, for subtracting from the spread-spectrum CDMA signal, all but a second one of the N spread-spectrum-processed-despread signals, thereby generating a second subtracted signal; and

an n^{th} subtractor, for subtracting from the spread-spectrum CDMA signal, all but an n^{th} one of the N spread-spectrum-processed-despread signals, thereby generating an n^{th} subtracted signal;

a first channel correlator for despreading the first subtracted signal with a first chip-code signal as an estimate of a first channel;

a second channel correlator for despreading the second subtracted signal with a second chip-code signal as an estimate of a second channel; and

an n^{th} channel correlator for despreading the n^{th} subtracted signal with an n^{th} chip-code signal as an estimate of an n^{th} channel.

24. A spread-spectrum code division multiple access (CDMA) interference canceler for reducing interference in a spread-spectrum CDMA receiver having N channels, with each of the N channels identified by a distinct chip-code signal, comprising:

a plurality of matched filters, responsive to a plurality of distinct chip-code-signals, for despreading, simultaneously, a plurality of spread-spectrum channels of a spread-spectrum CDMA signal as a plurality of despread signals, respectively;

a plurality of chip-code-signal generators, responsive to a plurality of despread signals from the plurality of matched filters, for generating, simultaneously, a timed plurality of chip-code signals, respectively;

a plurality of mixers, responsive to the plurality of despread signals from the plurality of matched filters and the timed plurality of chip-code signals from the plurality of chip-code-signal generators, respectively, for spread-spectrum processing, simultaneously, the plurality of despread signals, respectively, with a timed chip-code signal corresponding to a respective despread signal, producing N spread-spectrum-processed-despread signals;

a plurality of subtractors, each of said plurality of subtractors for subtracting from the spread-spectrum CDMA signal all but a particular one of the N spread-spectrum-processed-despread signals, with the particular one of the N spread-spectrum-processed-despread signals being different for each of said plurality of subtractors, thereby generating a plurality of subtracted signals; and

a plurality of channel-matched filters for despreading the plurality of subtracted signals with a particular one of the plurality of distinct chip-code signals, respectively, as a plurality of channels.

25. A spread-spectrum code division multiple access (CDMA) interference canceler for reducing interference in a spread-spectrum CDMA receiver having N channels, with each of the N channels identified by a distinct chip-code signal, comprising:

a plurality of matched filters, responsive to a plurality of distinct chip-code-signals, for simultaneously despreading a plurality of spread-spectrum channels of a spread-spectrum CDMA signal as a plurality of despread signals, respectively;

a plurality of chip-code-signal generators, responsive to a plurality of despread signals from the plurality of matched filters, for generating, simultaneously, a timed plurality of chip-code signals, respectively;

a plurality of mixers, responsive to the plurality of despread signals from the plurality of matched filters and the timed plurality of chip-code signals from the plurality of chip-code-signal generators, respectively, for spread-spectrum processing, simultaneously, the plurality of despread signals, respectively, with a timed chip-code signal corresponding to a respective despread signal, producing N spread-spectrum-processed-despread signals;

a first subtractor, for subtracting from the spread-spectrum CDMA signal, all but a first one of the N spread-spectrum-processed-despread signals, thereby generating a first subtracted signal;

a second subtractor, for subtracting from the spread-spectrum CDMA signal, all but a second one of the N spread-spectrum-processed-despread signals, thereby generating a second subtracted signal; and

an n^{th} subtractor, for subtracting from the spread-spectrum CDMA signal, all but an n^{th} one of the N spread-spectrum-processed-despread signals, thereby generating an n^{th} subtracted signal;

a first channel-matched filter for despreading the first subtracted signal with a first chip-code signal as an estimate of a first channel;

a second channel-matched filter for despreading the second subtracted signal with a second chip-code signal as an estimate of a second channel; and

an n^{th} channel-matched filter for despreading the n^{th} subtracted signal with an n^{th} chip-code signal as an estimate of an n^{th} channel.

* * * * *

US005553062A

United States Patent [19]

Schilling et al.

[11] **Patent Number: 5,553,062**

[45] **Date of Patent: Sep. 3, 1996**

[54] **SPREAD SPECTRUM CDMA INTERFERENCE CANCELER SYSTEM AND METHOD**

[75] Inventors: **Donald L. Schilling**, Sands Point; **John Kowalski**; **Shimon Moshavi**, both of New York, all of N.Y.

[73] Assignee: **InterDigital Communication Corporation**, Wilmington, Del.

[21] Appl. No.: **279,477**

[22] Filed: **Jul. 26, 1994**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 51,017, Apr. 22, 1993, Pat. No. 5,363,403.

[51] **Int. Cl.**[6] **H04B 1/707**; H04T 13/04

[52] **U.S. Cl.** **370/18**; 375/205; 375/207; 375/343; 375/346; 380/34

[58] **Field of Search** 370/18; 375/200, 375/205, 206, 207, 208–210, 343, 346; 380/34

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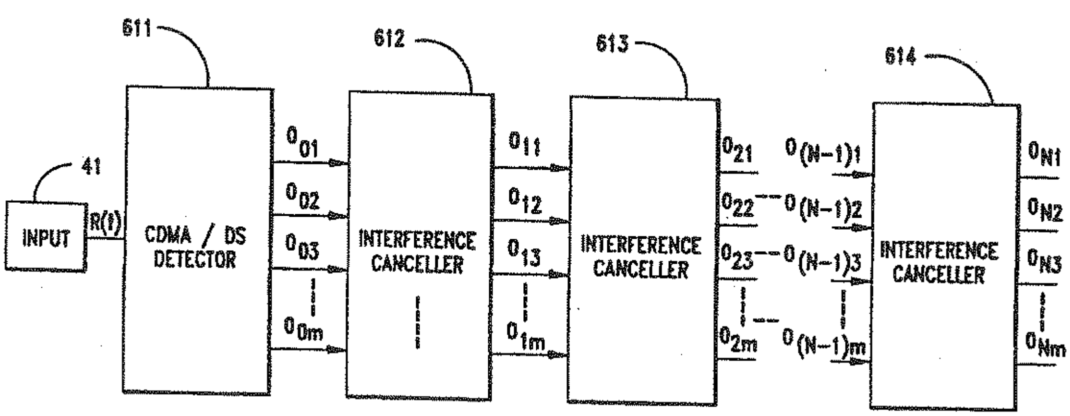
Assistant Examiner—Seema S. Rao
Attorney, Agent, or Firm—David Newman & Associates, P.C.

[57] **ABSTRACT**

A spread-spectrum code division multiple access interference canceler system and method for reducing interference in a spread-spectrum CDMA receiver having N chip-code channels, with each of the N channels identified by a distinct chip-code signal. The interference canceler system comprises a plurality of interference cancelers, each having chip-code generators, delay devices, correlators, spread-spectrum-processing circuits, and subtracting means. Using a plurality of chip-code signals, the correlators despread the spread-spectrum CDMA signal as a plurality of despread signals, respectively. The spread-spectrum-processing circuits use a timed version of the plurality of chip-code signals, generated by the delay devices, for spread-spectrum processing the plurality of despread signals, respectively, with a timed chip-code-signal corresponding to a respective despread signal. For recovering a channel, subtracting means subtracts the spread-spectrum-processed-despread signals other than the signal of the desired channel of the spread-spectrum CDMA signal. The system may further comprise a CDMA/DS detector for receiving a spread-spectrum signal, a plurality of interference cancelers connected in series for generating a plurality of estimates of the spread-spectrum signal, combining means for combining the estimates as averaged estimates, and decision means for receiving the averaged estimates.

22 Claims, 14 Drawing Sheets



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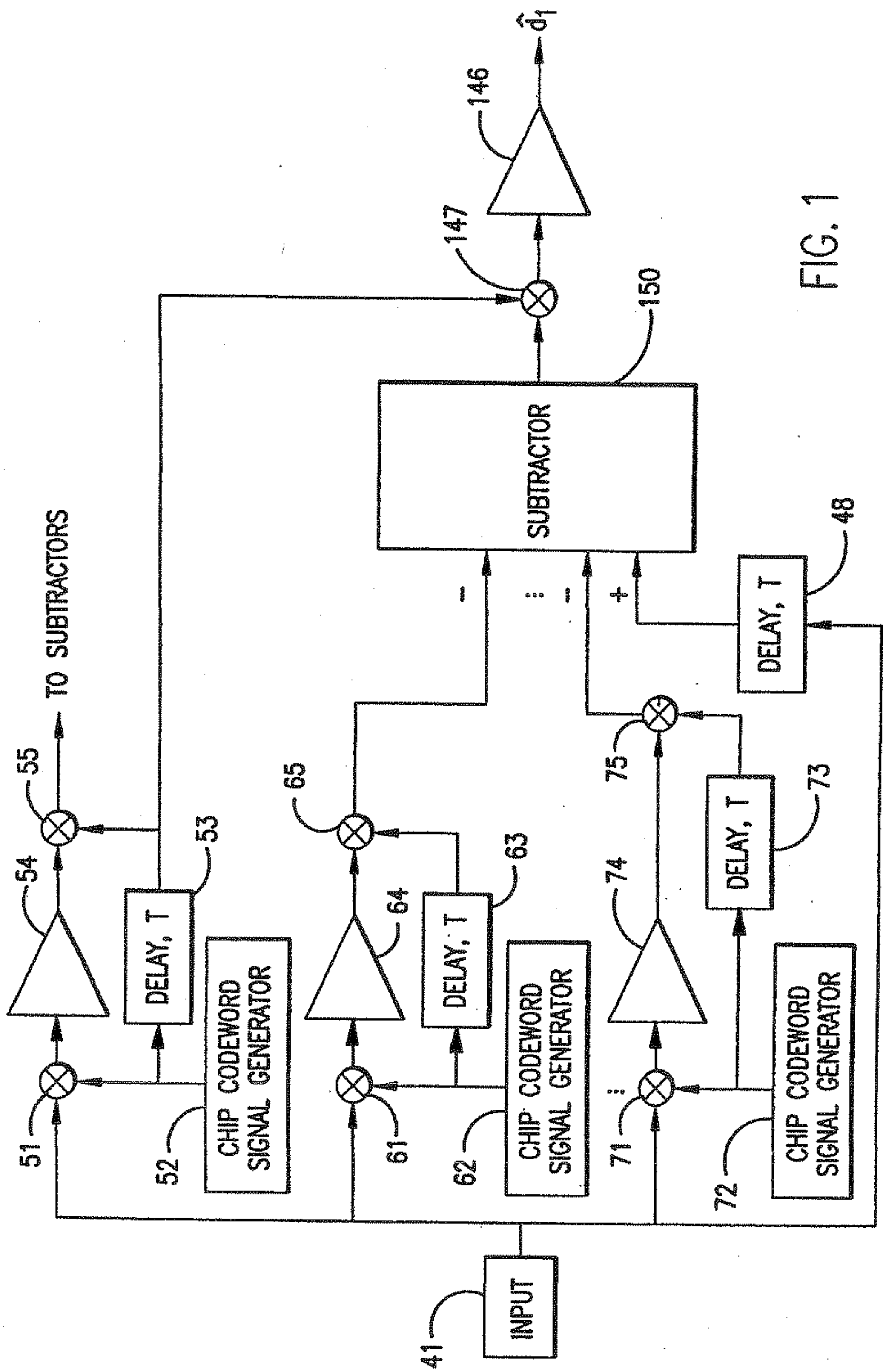
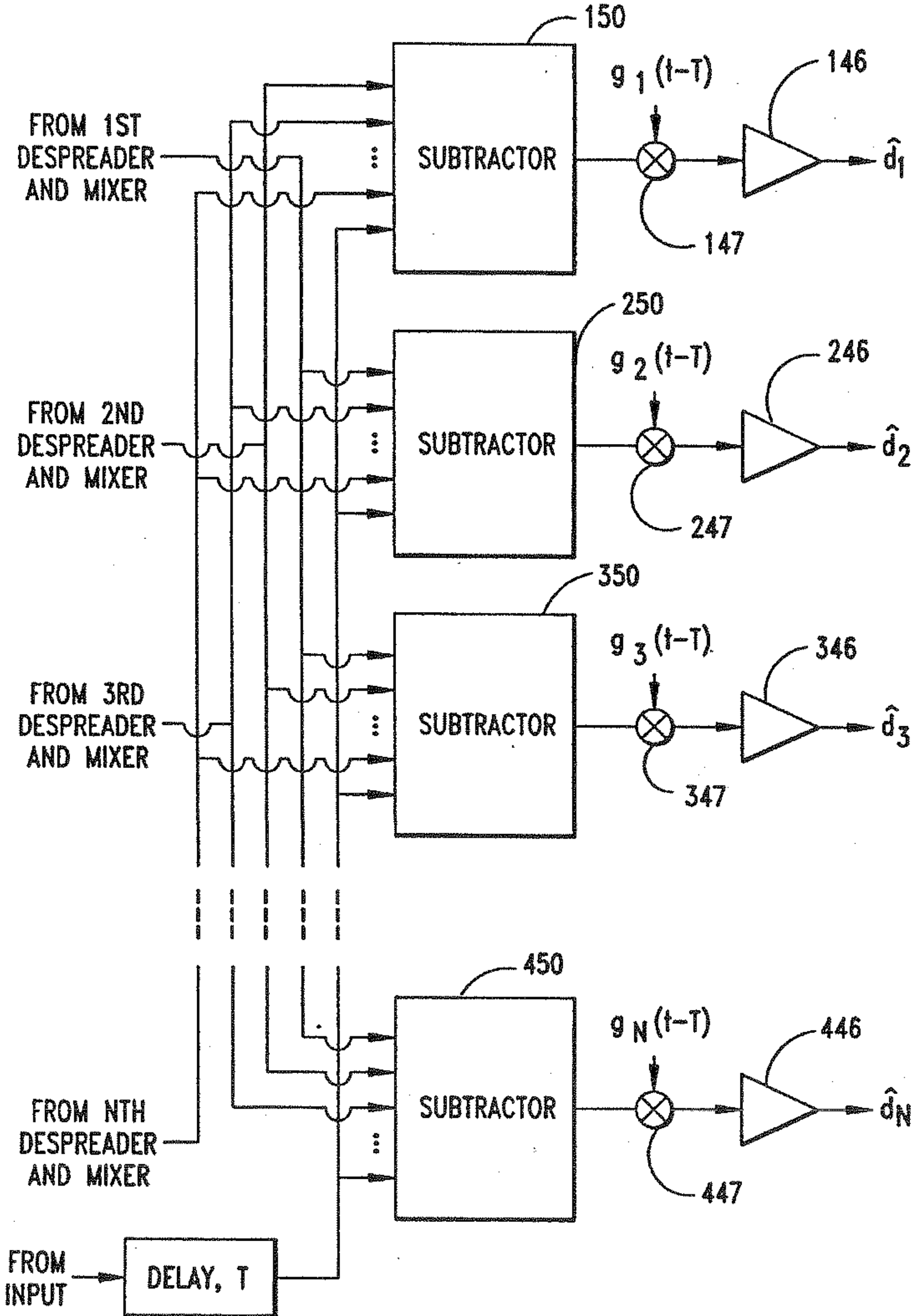

41
INPUT
51
52
CHIP CODEWORD SIGNAL GENERATOR
53
DELAY, T
54
55
TO SUBTRACTORS
61
62
CHIP CODEWORD SIGNAL GENERATOR
63
DELAY, T
64
65
71
72
CHIP CODEWORD SIGNAL GENERATOR
73
DELAY, T
74
75
48
DELAY, T
SUBTRACTOR
150
147
146
$\hat{d}_1$
−
−
+

FIG. 1



150
SUBTRACTOR
$g_1(t-T)$
146
147
$\hat{d}_1$
FROM 1ST DESPREADER AND MIXER
250
SUBTRACTOR
$g_2(t-T)$
246
247
$\hat{d}_2$
FROM 2ND DESPREADER AND MIXER
350
SUBTRACTOR
$g_3(t-T)$
346
347
$\hat{d}_3$
FROM 3RD DESPREADER AND MIXER
450
SUBTRACTOR
$g_N(t-T)$
446
447
$\hat{d}_N$
FROM NTH DESPREADER AND MIXER
FROM INPUT
DELAY, T

FIG. 2

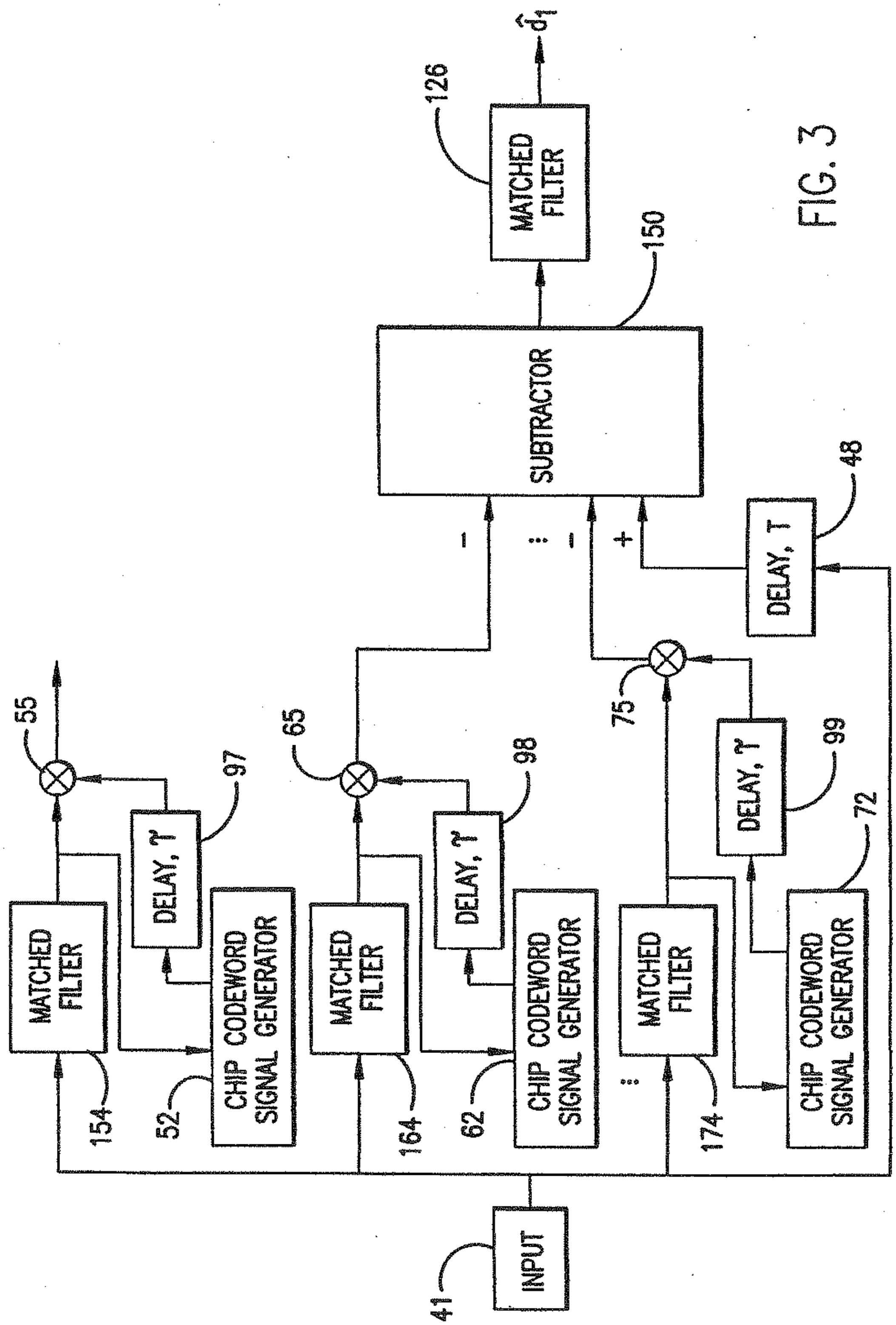
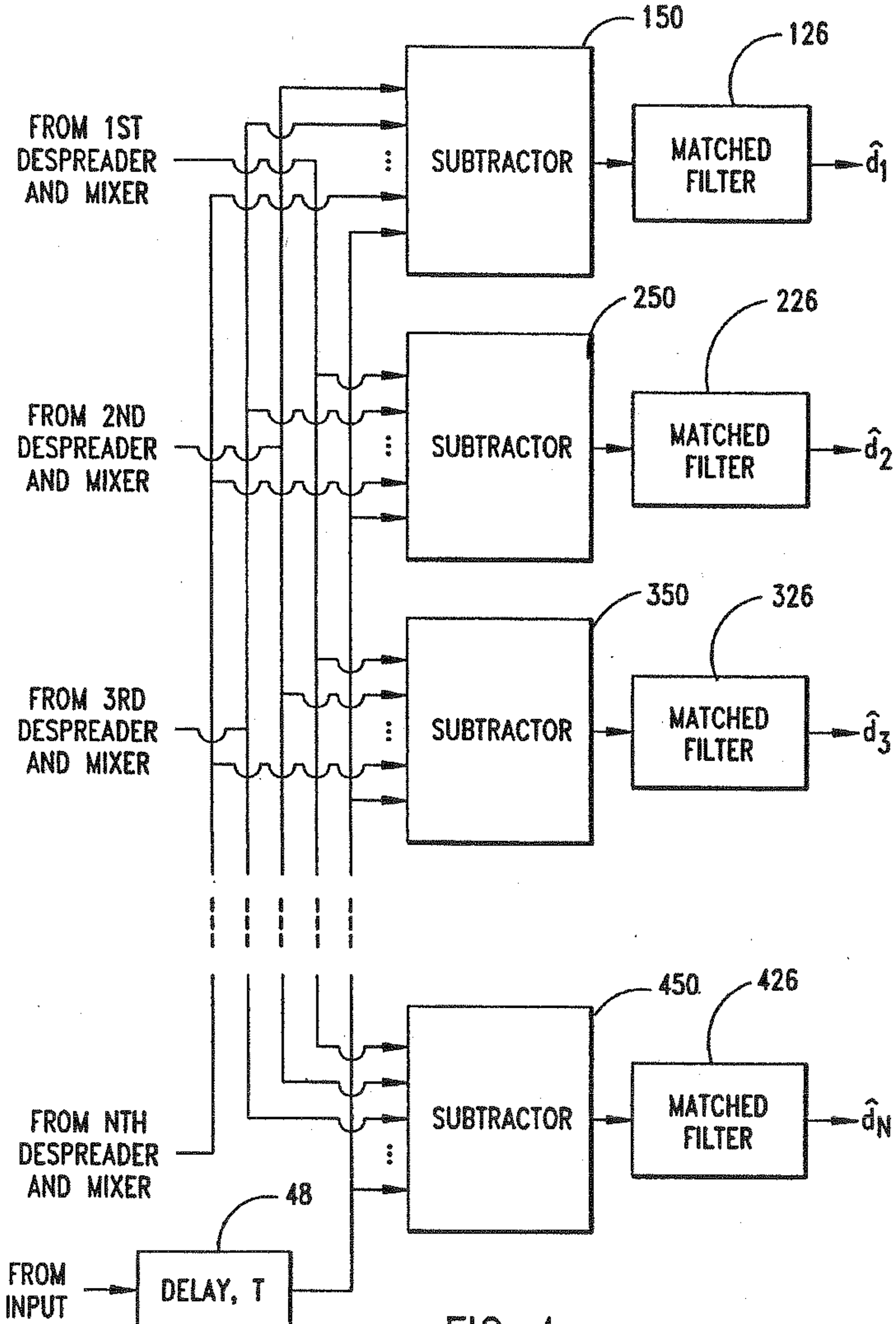
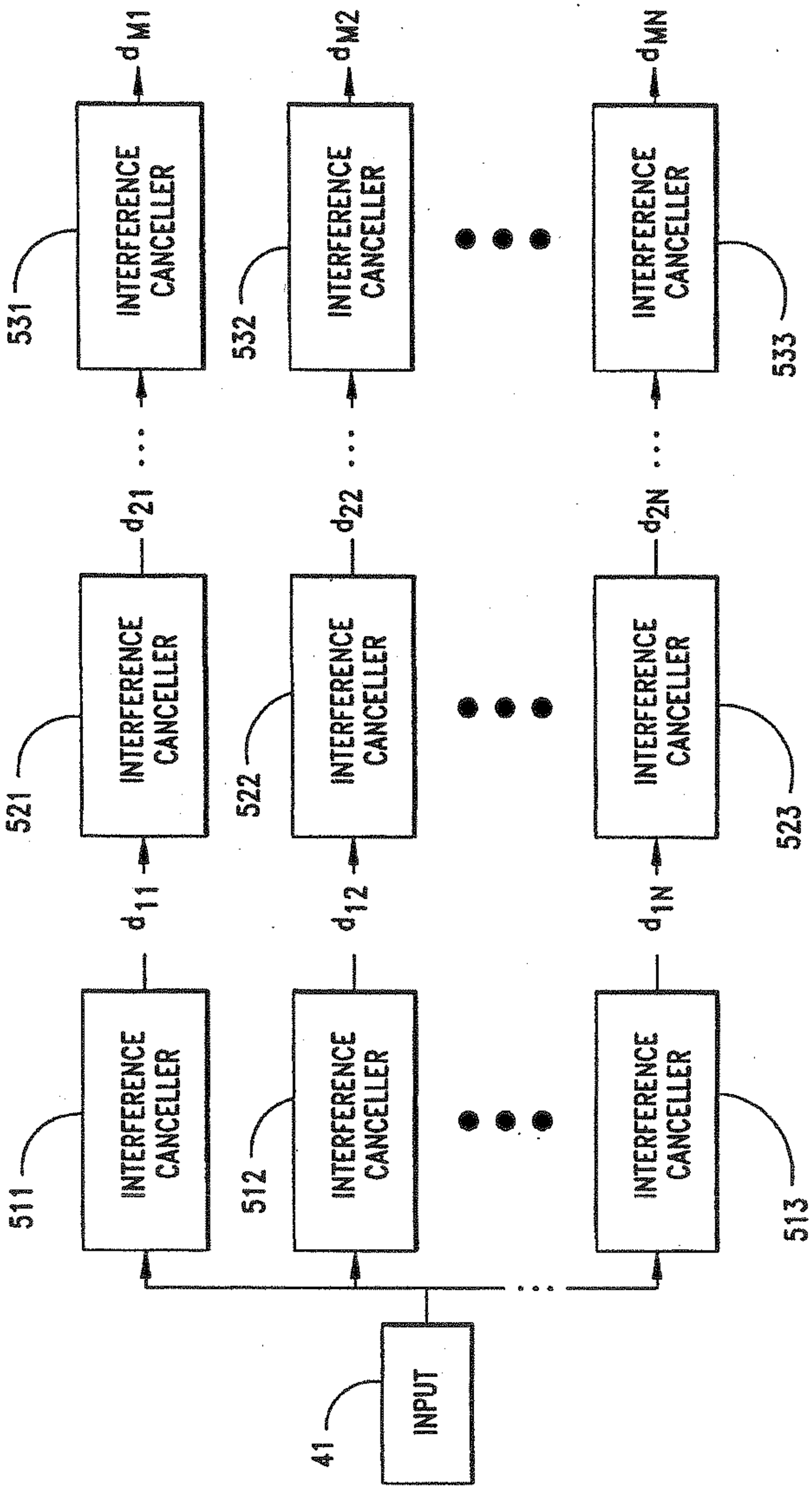

MATCHED FILTER
126
$\hat{d}_1$
150
SUBTRACTOR
48
DELAY, T
+
–
–
55
65
75
97
98
99
72
DELAY, τ
DELAY, τ
DELAY, τ
MATCHED FILTER
MATCHED FILTER
MATCHED FILTER
CHIP CODEWORD SIGNAL GENERATOR
CHIP CODEWORD SIGNAL GENERATOR
CHIP CODEWORD SIGNAL GENERATOR
154
52
164
62
174
INPUT
41

FIG. 3



150
126
FROM 1ST DESPREADER AND MIXER
SUBTRACTOR
MATCHED FILTER
$\hat{d}_1$
250
226
FROM 2ND DESPREADER AND MIXER
SUBTRACTOR
MATCHED FILTER
$\hat{d}_2$
350
326
FROM 3RD DESPREADER AND MIXER
SUBTRACTOR
MATCHED FILTER
$\hat{d}_3$
450
426
FROM NTH DESPREADER AND MIXER
SUBTRACTOR
MATCHED FILTER
$\hat{d}_N$
48
FROM INPUT
DELAY, T

FIG. 4



41
INPUT
511
512
513
INTERFERENCE CANCELLER
INTERFERENCE CANCELLER
INTERFERENCE CANCELLER
d_{11}
d_{12}
d_{1N}
521
522
523
INTERFERENCE CANCELLER
INTERFERENCE CANCELLER
INTERFERENCE CANCELLER
d_{21}
d_{22}
d_{2N}
531
532
533
INTERFERENCE CANCELLER
INTERFERENCE CANCELLER
INTERFERENCE CANCELLER
d_{M1}
d_{M2}
d_{MN}

FIG. 5

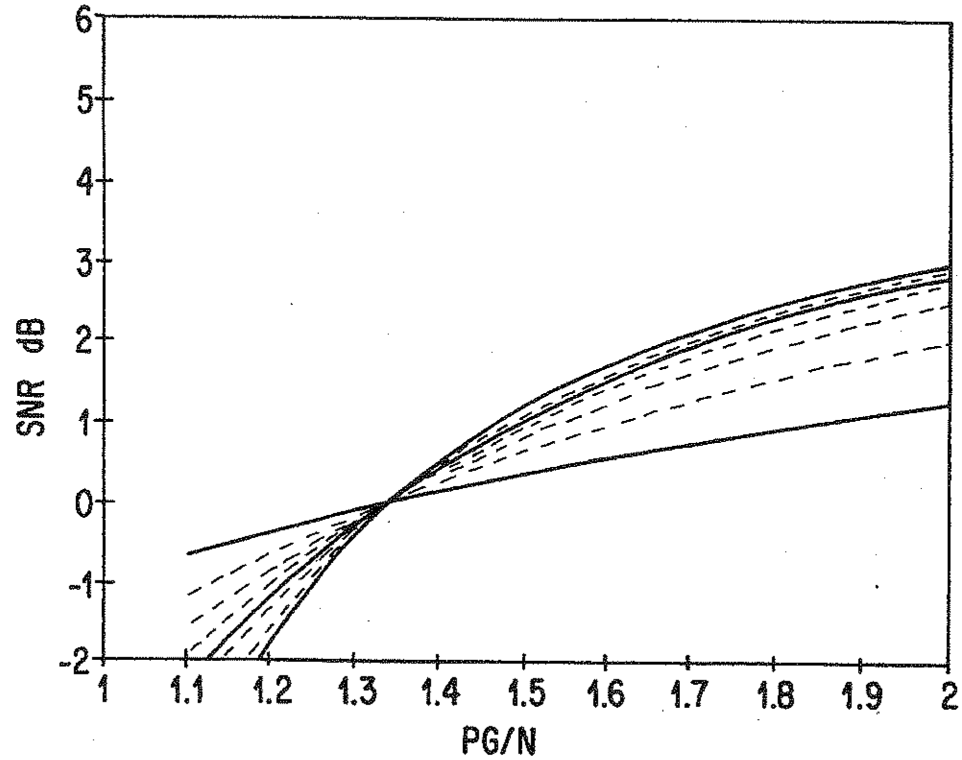

6
5
4
3
2
1
0
-1
-2
SNR dB
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

FIG.6

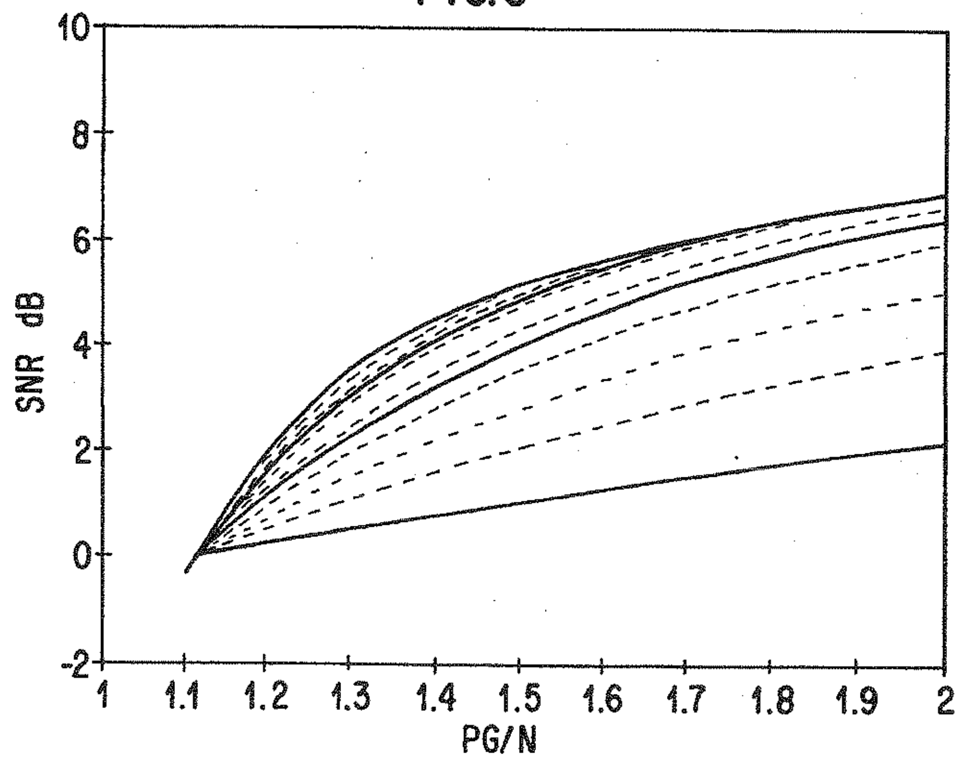

10
8
6
4
2
0
-2
SNR dB
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

FIG.7

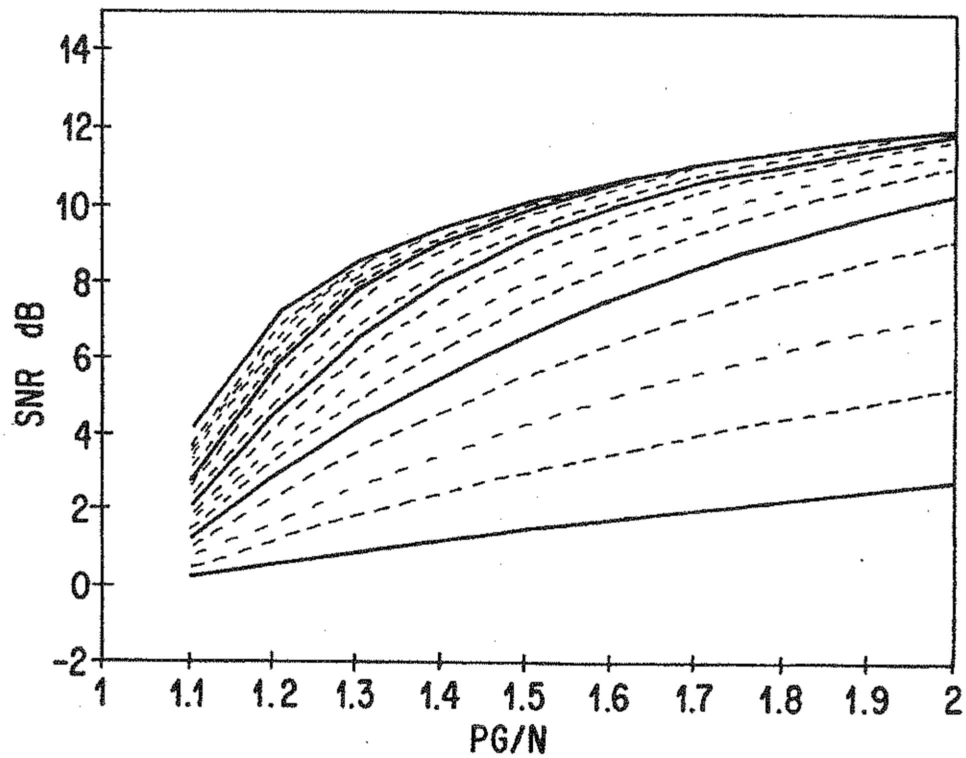

14
12
10
8
6
4
2
0
-2
SNR dB
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

FIG. 8

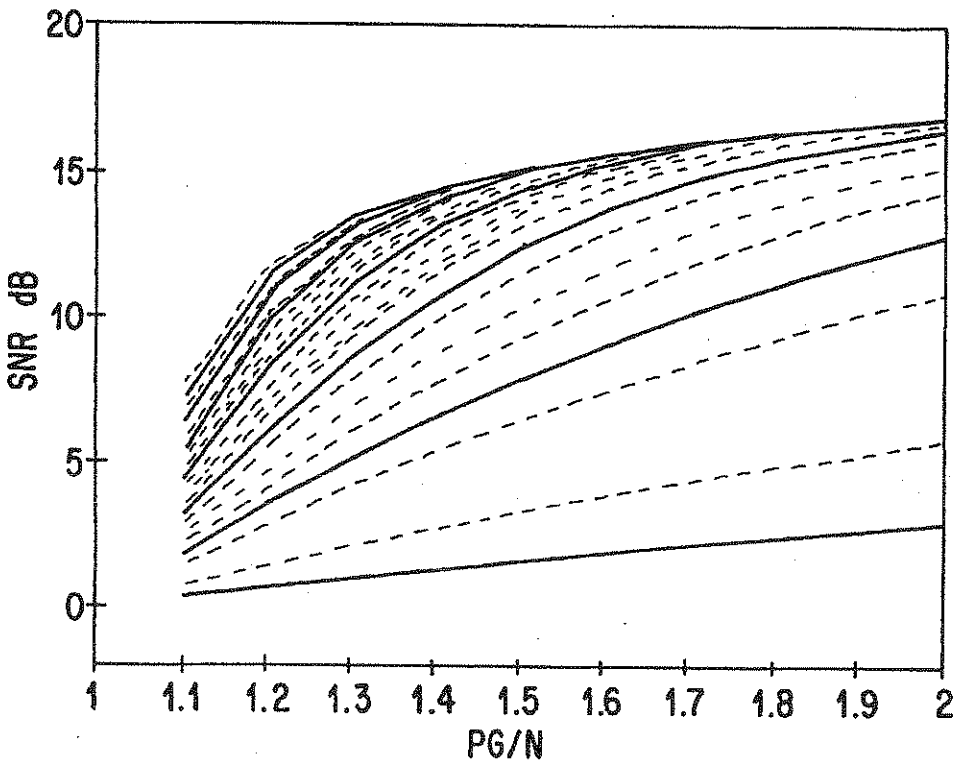
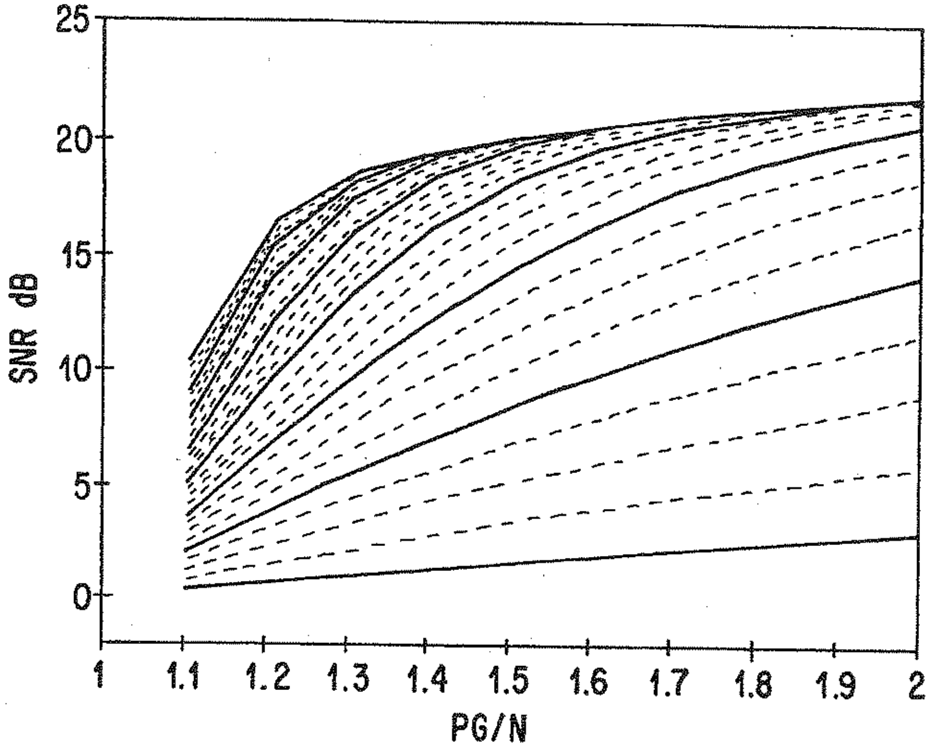
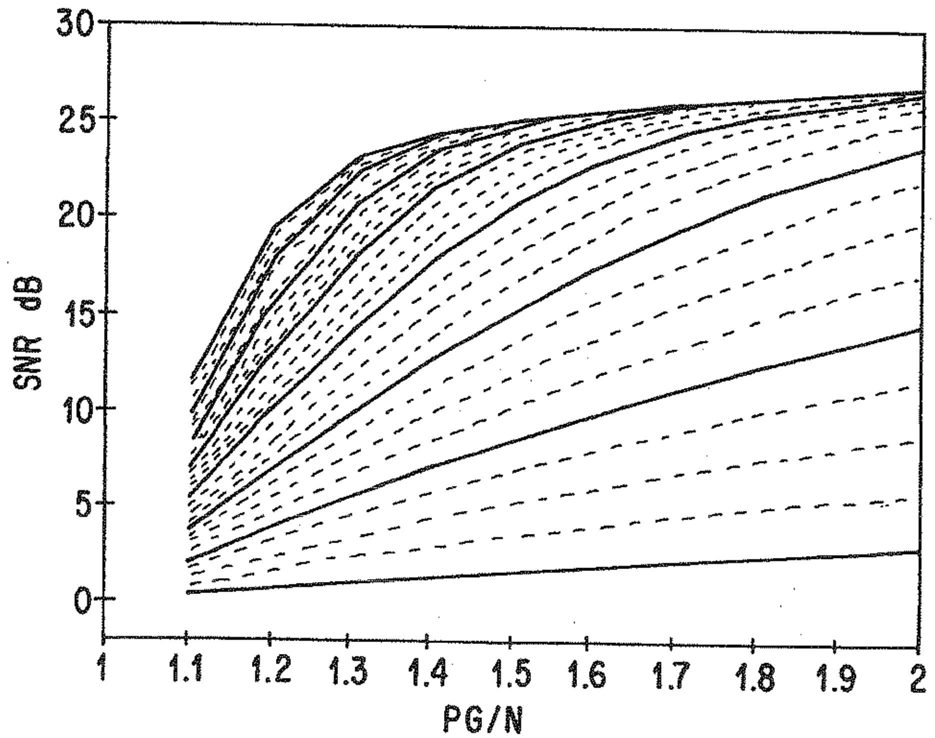

20
15
10
5
0
SNR dB
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

FIG. 9



25
20
15
10
5
0
SNR dB
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

FIG.10



30
25
20
15
10
5
0
SNR dB
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

FIG.11

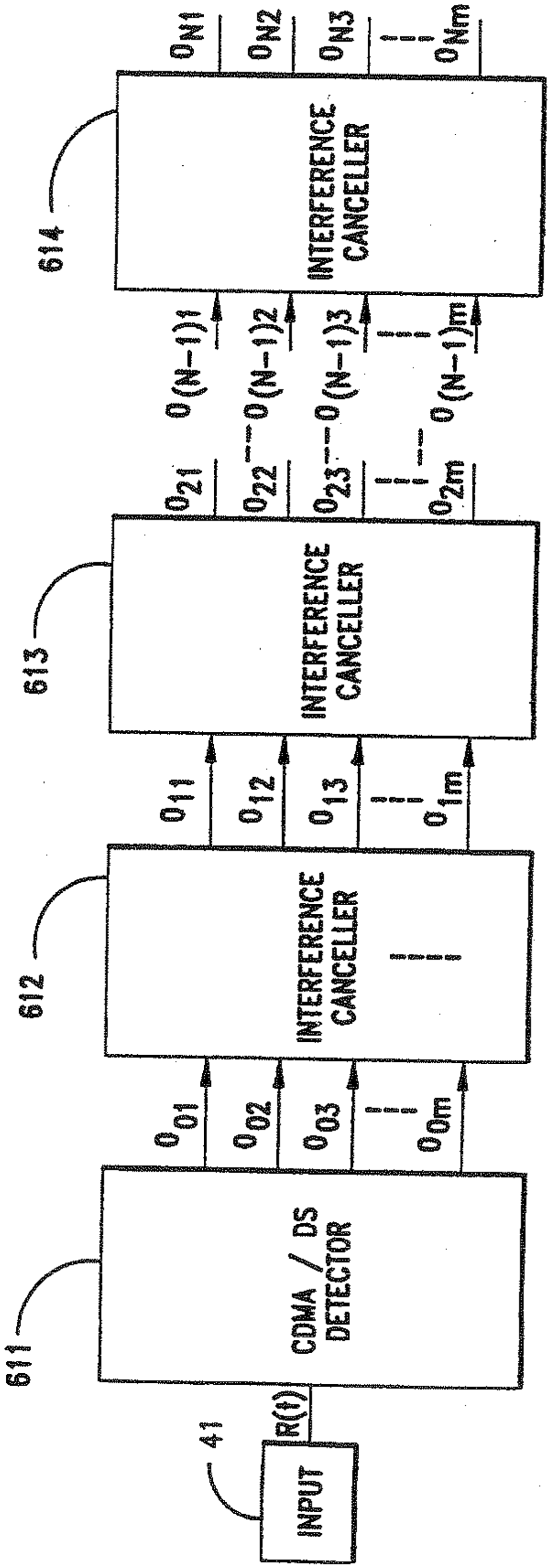

41
INPUT
R(t)
611
CDMA / DS DETECTOR
612
INTERFERENCE CANCELLER
613
INTERFERENCE CANCELLER
614
INTERFERENCE CANCELLER

FIG. 12

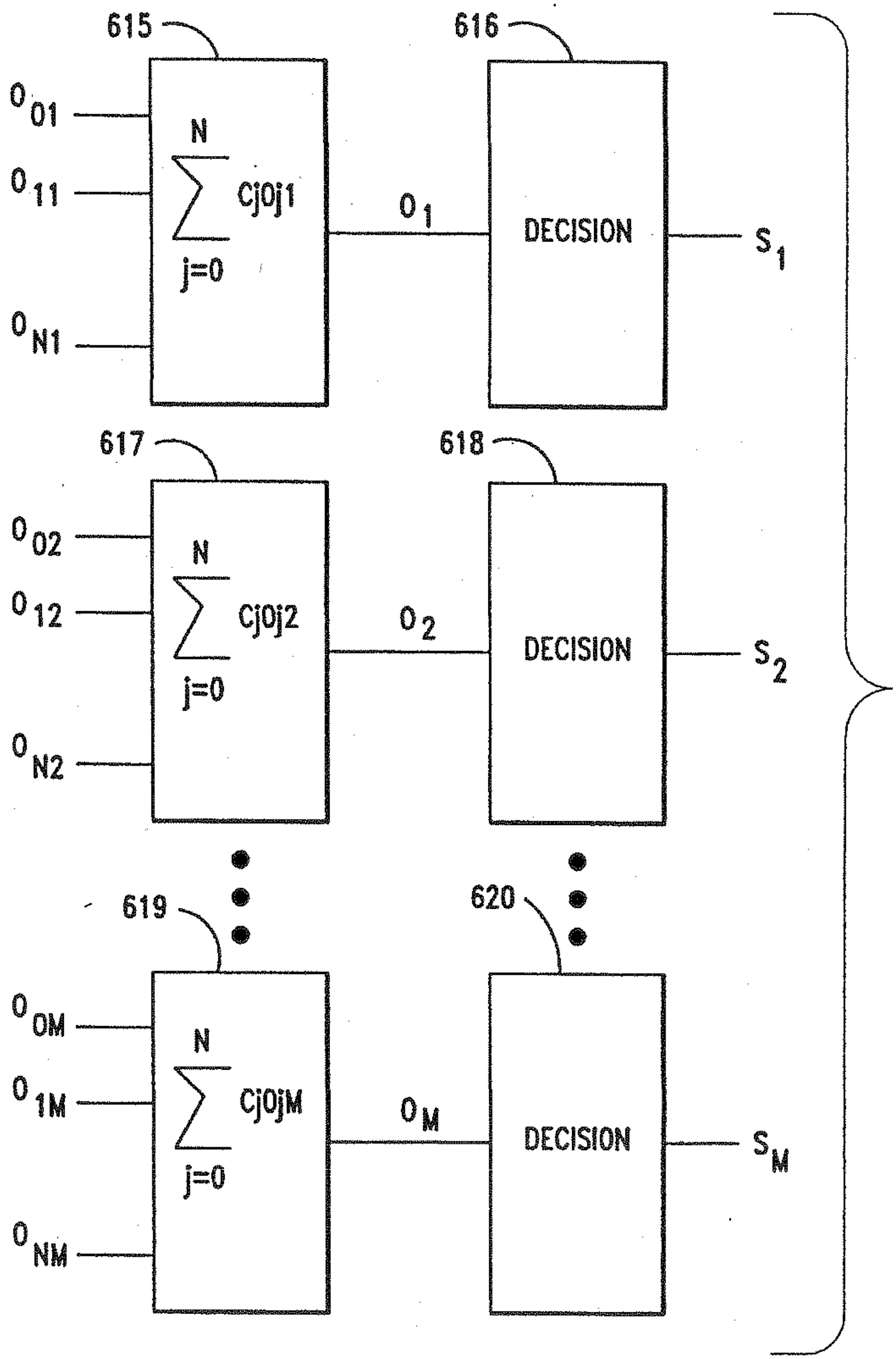

615
616
0 01
0 11
0 N1
N
j=0
Cj0j1
0 1
DECISION
S 1
617
618
0 02
0 12
0 N2
Cj0j2
0 2
S 2
619
620
0 0M
0 1M
0 NM
Cj0jM
0 M
S M

FIG. 13

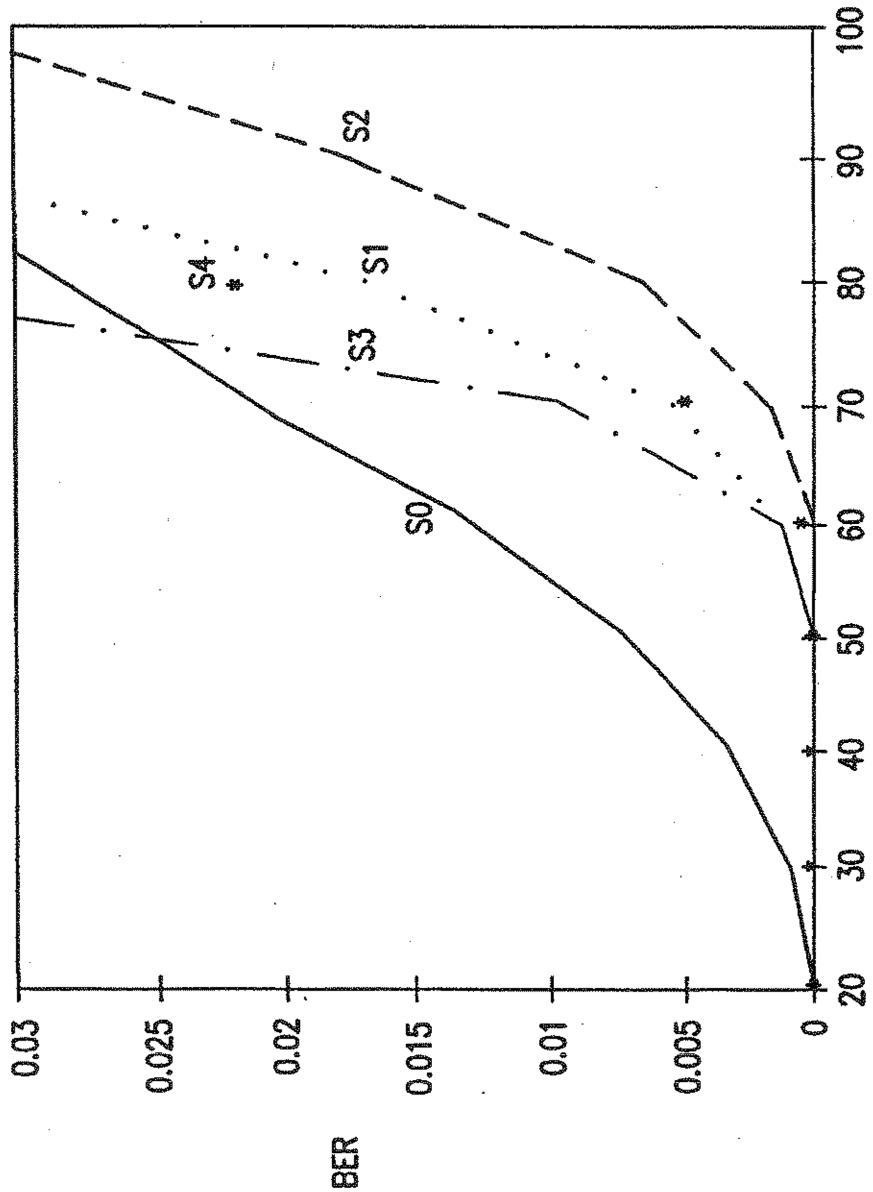

S2
S1
S4
S3
S0
BER
0.03
0.025
0.02
0.015
0.01
0.005
0
USERS
20
30
40
50
60
70
80
90
100

FIG. 14

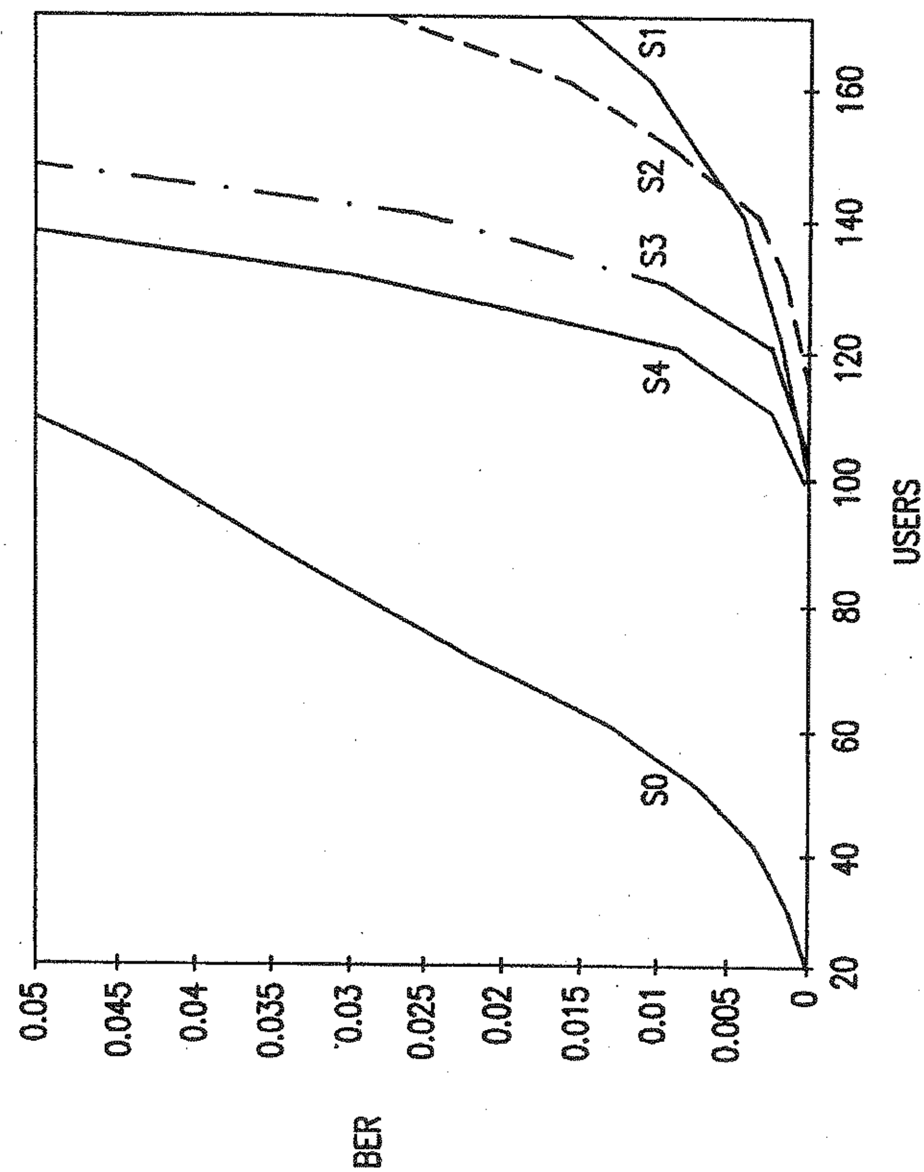

BER
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
USERS
20
40
60
80
100
120
140
160
S0
S1
S2
S3
S4

FIG. 15

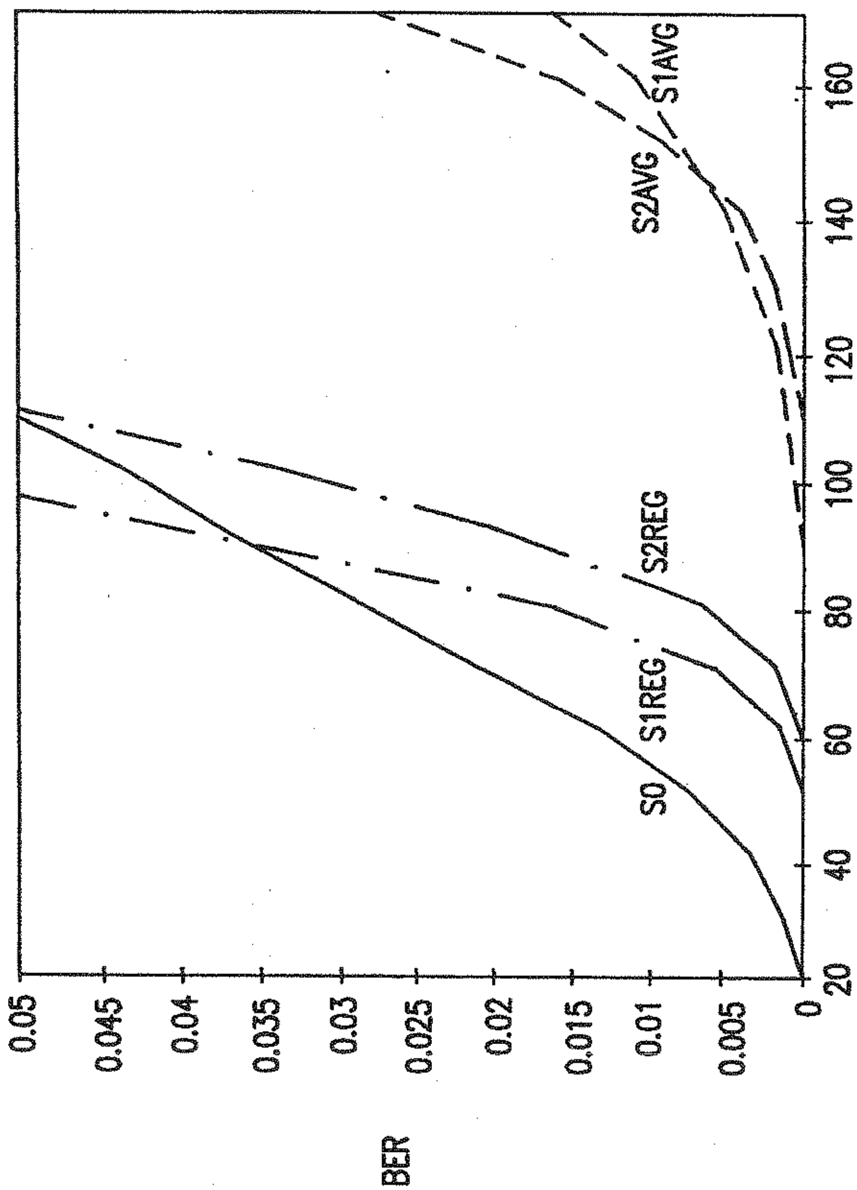

BER
USERS
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
20
40
60
80
100
120
140
160
S0
S1REG
S2REG
S2AVG
S1AVG

FIG. 16

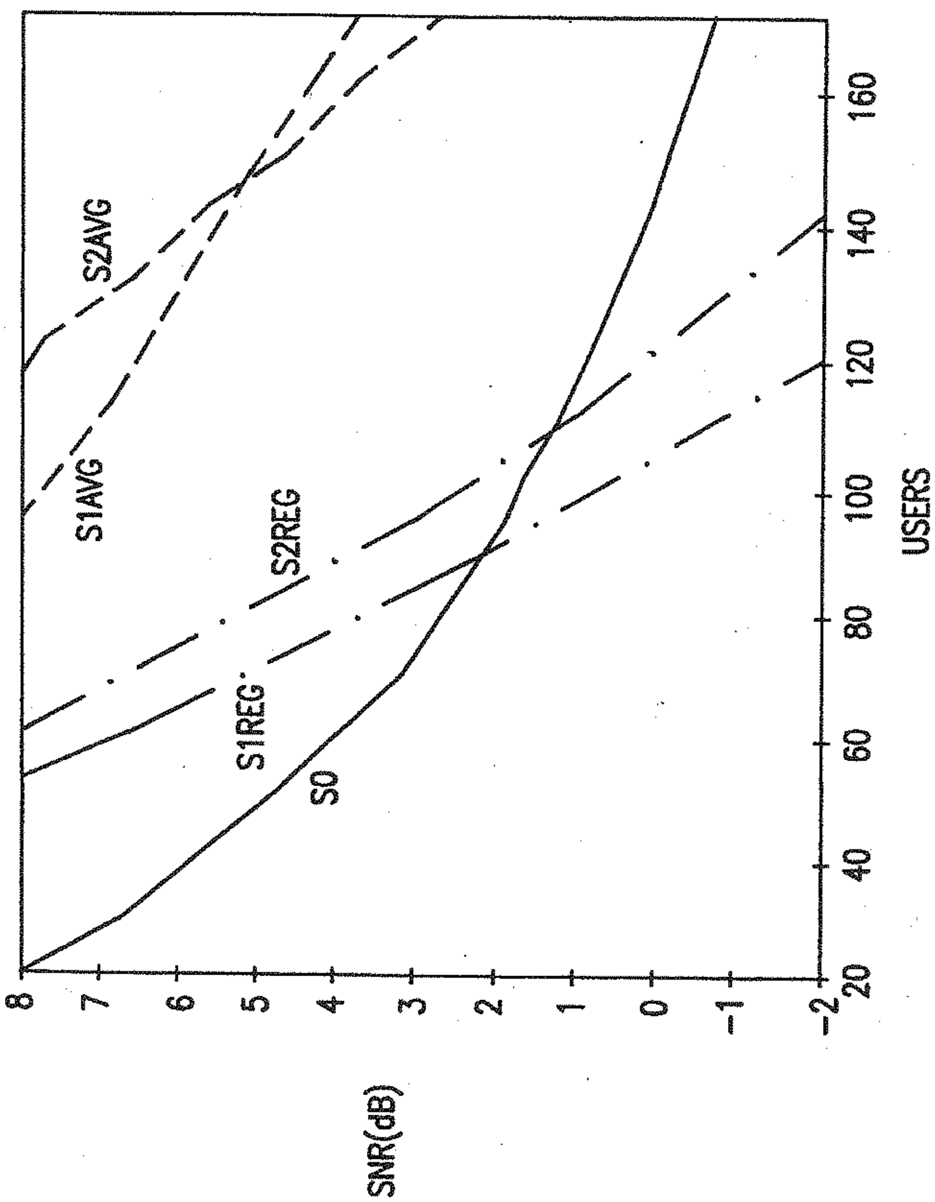

S2AVG
S1AVG
S2REG
S1REG
S0
SNR(dB)
USERS
8
7
6
5
4
3
2
1
0
−1
−2
20
40
60
80
100
120
140
160

FIG. 17

SPREAD SPECTRUM CDMA INTERFERENCE CANCELER SYSTEM AND METHOD

RELATED PATENTS

This patent issued from continuation-in-part patent application of a patent application entitled, SPREAD SPECTRUM CDMA SUBTRACTIVE INTERFERENCE CANCELER AND METHOD, having Ser. No. 08/051,017, and filing data Apr. 22, 1993, U.S. Pat. No. 5,363,403. The benefit of the earlier filing date of the parent patent application is claimed pursuant to 35 U.S.C.§120.

BACKGROUND OF THE INVENTION

This invention relates to spread-spectrum communications, and more particularly to an interference canceler and method for reducing interference in a direct sequence, code division multiple access receiver

DESCRIPTION OF THE RELEVANT ART

Direct sequence, code division multiple access, spread-spectrum communications systems are capacity limited by interference caused by other simultaneous users. This is compounded if adaptive power control is not used, or is used but is not perfect.

Code division multiple access is interference limited. The more users transmitting simultaneously, the higher the bit error rate (BER). Increased capacity requires forward error correction (FEC) coding, which in turn, increases the data rate and limits capacity.

SUMMARY OF THE INVENTION

A general object of the invention is to reduce noise resulting from N–1 interfering signals in a direct sequence, spread-spectrum code division multiple access receiver.

The present invention, as embodied and broadly described herein, provides a spread-spectrum code division multiple access (CDMA) interference canceler for reducing interference in a spread-spectrum CDMA receiver having N channels. Each of the N channels is spread-spectrum processed by a distinct chip-code signal. The chip-code signal, preferably, is derived from a distinct pseudo-noise (PN) sequence, which may be generated from a distinct chip codeword. The interference canceler partially cancels N–1 interfering CDMA channels, and provides a signal-to-noise ratio (SNR) improvement of approximately N/PG, where PG is the processing gain. Processing gain is the ratio of the chip rate divided by the bit rate. By canceling or reducing interference, the SNR primarily may be due to thermal noise, and residual, interference-produced noise. Thus, the SNR may increase, lowering the BER, which reduces the demand for a FEC encoder/decoder.

The interference canceler, for a particular channel, includes a plurality of despreading means, a plurality of spread-spectrum-processing means, subtracting means, and channel-despreading means. Using a plurality of chip-code signals, the plurality of despreading means despreads the spread-spectrum CDMA signals as a plurality of despread signals, respectively. The plurality of spread-spectrum-processing means uses a timed version of the plurality of chip-code signals, for spread-spectrum processing the plurality of despread signals, respectively, with a chip-code signal corresponding to a respective despread signal. The timed version of a chip-code signal may be generated by delaying the chip-code signal from a chip-code-signal generator. Alternatively, a matched filter may detect a particular PN sequence in the spread-spectrum CDMA signal. A chip-code-signal generator may use the detected signal from the matched filter to trigger a timed version of the chip-code signal.

For recovering a particular CDMA channel using an i^{th} chip-code signal, the subtracting means subtracts from the spread-spectrum CDMA signal, each of the N–1 spread-spectrum-processed-despread signals, thereby generating a subtracted signal. The N–1 spread-spectrum-processed-despread signals do not include the spread-spectrum-processed-despread signal of the i^{th} channel corresponding to the i^{th} chip-code signal. The channel-despreading means despreads the subtracted signal with the i^{th} chip-code signal.

The present invention also includes a method for reducing interference in a spread-spectrum CDMA receiver having N channels. The method comprises the steps of despreading, using a plurality of chip-code signals, the spread-spectrum CDMA signal as a plurality of despread signals, respectively; spread-spectrum processing, using a timed version of the plurality of chip-code signals, the plurality of despread signals, respectively, with a chip-code signal corresponding to a respective despread signal; subtracting from the spread-spectrum CDMA signal, each of the N–1 spread-spectrum-processed-despread signals, with the N–1 spread-spectrum-processed-despread signals not including a spread-spectrum-processed despread signal of the i^{th} channels, thereby generating a subtracted signal; and, despreading the subtracted signal having the i^{th} chip-code signal.

Additional objects and advantages of the invention are set forth in part in the description which follows, and in part are obvious from the description, or may be learned by practice of the invention. The objects and advantages of the invention also may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate preferred embodiments of the invention, and together with the description serve to explain the principles of the invention.

FIG. 1 is a block diagram of the spread-spectrum CDMA interference canceler using correlators;

FIG. 2 is a block diagram of the spread-spectrum CDMA interference canceler for processing multiple channels using correlators;

FIG. 3 is a block diagram of the spread-spectrum CDMA interference canceler using matched filters;

FIG. 4 is a block diagram of the spread-spectrum CDMA interference canceler for processing multiple channels using matched filters;

FIG. 5 is a block diagram of the spread-spectrum CDMA interference canceler having multiple iterations for processing multiple channels;

FIG. 6 illustrates theoretical performance characteristic for E_b/η=6 dB;

FIG. 7 illustrates theoretical performance characteristic for E_b/η=10 dB;

FIG. 8 illustrates theoretical performance characteristic for E_b/η=15 dB;

FIG. 9 illustrates theoretical performance characteristic for E_b/η=20 dB;

FIG. 10 illustrates theoretical performance characteristic for E_b/η=25 dB; and

FIG. 11 illustrates theoretical performance characteristic for E_b/η=30 dB;

FIG. 12 is a block diagram of interference cancelers connected together;

FIG. 13 is a block diagram combining the outputs of the interference cancelers of FIG. 12;

FIG. 14 illustrates simulation performance characteristics for asynchronous, PG=100, Equal Powers, EbN=30 dB;

FIG. 15 illustrates simulation performance characteristics for asynchronous, PG=100, Equal Powers, EbN=30 dB;

FIG. 16 illustrates simulation performance characteristics for asynchronous, PG=100, Equal Powers, EbN=30 dB; and

FIG. 17 illustrates simulation performance characteristics for asynchronous, PG=100, Equal Powers, EbN=30 dB.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference now is made in detail to the present preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings, wherein like reference numerals indicate like elements throughout the several views.

In the exemplary arrangement shown in FIG. 1, a spread-spectrum code division multiple access (CDMA) interference canceler is provided for reducing interference in a spread-spectrum CDMA receiver having N channels. The present invention also works on a spread-spectrum code division multiplexed (CDM) system. Accordingly, without loss of generality, the term spread-spectrum CDMA signal, as used herein, includes spread-spectrum CDMA signals and spread-spectrum CDM signals. In a personal communications service, the interference canceler may be used at a base station or in a remote unit such as a handset.

FIG. 1 illustrates the interference canceler for the first channel, defined by the first chip-code signal. The interference canceler includes a plurality of despreading means, a plurality of timing means, a plurality of spread-spectrum-processing means, subtracting means, and first channel-despreading means.

Using a plurality of chip-code signals, the plurality of despreading means despreads the received spread-spectrum CDMA signals as a plurality of despread signals, respectively. In FIG. 1 the plurality of despreading means is shown as first despreading means, second despreading means, through N^{th} despreading means. The first despreading means includes a first correlator, which is embodied, by way of example, as a first mixer **51**, first chip-code-signal generator **52**, and a first integrator **54**. The first integrator **54** alternatively may be a first lowpass filter or a first bandpass filter. The first mixer **51** is coupled between the input **41** and the first chip-code-signal generator **52** and the first integrator **54**.

The second despreading means includes a second correlator, which is embodied, by way of example, as second mixer **61**, second chip-code-signal generator **62** and second integrator **64**. The second integrator **64** alternatively may be a second lowpass filter or a second bandpass filter. The second mixer **61**, is coupled between the input **41**, the second chip-code-signal generator **62**, and the second integrator **64**.

The N^{th} despreading means is depicted as an N^{th} correlator shown, by way of example, as N^{th} mixer **71**, and N^{th} chip-code-signal generator **72**, and N^{th} integrator **74**. The N^{th} integrator **74** alternatively may be an N^{th} lowpass filter or an N^{th} bandpass filter. The N^{th} mixer **71** is coupled between the input **41**, the N^{th} chip-code-signal generator **72** and the N^{th} integrator **74**.

As is well known in the art, the first through N^{th} despreading means may be embodied as any device which can despread a channel in a spread-spectrum signal.

The plurality of timing means may be embodied as a plurality of delay devices **53**, **63**, **73**. A first delay device **53** has a delay time T, which is approximately the same as the integration time T_b of first integrator **54**, or time constant of the first lowpass filter or first bandpass filter. A second delay device **63** has a time delay T, which is approximately the same as the integration time T_b of second integrator **64**, or time constant of the second lowpass filter or second bandpass filter. Similarly, the N^{th} delay device **73** has a time delay T, which is approximately the same as the integration time T_b of N^{th} integrator **74**, or time constant of the N^{th} lowpass filter or N^{th} bandpass filter. Typically, the integration times of the first integrator **54**, second integrator **64** through N^{th} integrator **74** are the same. If lowpass filters are used, then typically the time constants of the first lowpass filter, second lowpass filter through N^{th} lowpass filter are the same. If bandpass filters are used, then the time constants of the first bandpass filter, second bandpass filter through N^{th} bandpass filter are the same.

The plurality of spread-spectrum-processing means regenerates each of the plurality of despread signals as a plurality of spread-spectrum signals. The plurality of spread-spectrum-processing means uses a timed version, i.e. delayed version, of the plurality of chip-code signals, for spread-spectrum processing the plurality of despread signals, respectively, with a chip-code signal corresponding to a respective despread signal. The plurality of spread-spectrum-processing means is shown, by way of example, as a first processing mixer **55**, a second processing mixer **65**, through an N^{th} processing mixer **75**. The first processing mixer **55** is coupled to the first integrator **54**, and through a first delay device **53** to the first chip-code-signal generator **52**. The second processing mixer **65** is coupled to the second integrator **64**, and through the second delay device **63** to the second chip-code-signal generator **62**. The N^{th} processing mixer **75** is coupled to the N^{th} integrator **74** through the delay device **73** to the N^{th} chip-code-signal generator **72**.

For reducing interference to a channel using an i^{th} chip-code signal of the spread-spectrum CDMA signal, the subtracting means subtracts, from the spread-spectrum CDMA signal, each of the N–1 spread-spectrum-processed-despread signals not corresponding to the i^{th} channel. The subtracting means thereby generates a subtracted signal. The subtracting means is shown as a first subtractor **150**. The first subtractor **150** is shown coupled to the output of the second processing mixer **65**, through the N^{th} processing mixer **75**. Additionally, the first subtractor **150** is coupled through a main delay device **48** to the input **41**.

The i^{th} channel-despreading means despreads the subtracted signal with the i^{th} chip-code signal as the i^{th} channel. The first channel-despreading means is shown as a first channel mixer **147**. The first channel mixer **147** is coupled to the first delay device **53**, and to the first subtractor **150**. The first channel integrator **146** is coupled to the first channel mixer **147**.

The first chip-code-signal generator **52**, the second chip-code-signal generator **62**, through the N^{th} chip-code-signal generator **72** generate a first chip-code signal, a second chip-code signal, through a N^{th} chip-code signal, respec-

tively. The term "chip-code signal" is used herein to mean the spreading signal of a spread-spectrum signal, as is well known in the art. Typically the chip-code signal is generated from a pseudorandom (PN) sequence. The first chip-code signal, the second chip code signal, through the N^{th} chip-code signal might be generated from a first PN sequence, a second PN sequence, through a N^{th} PN sequence, respectively. The first PN sequence is defined by or generated from a first chip codeword, the second PN sequence is defined by or generated from a second chip codeword, through the N^{th} PN sequence is defined by or generated from a N^{th} chip-codeword. Each of the first chip codeword, second chip codeword through N^{th} chip codeword is distinct, i.e. different from one another. In general, a chip codeword can be the actual sequence of a PN sequence, or used to define settings for generating the PN sequence. The settings might be the delay taps of shift registers, for example.

A first channel of a received spread-spectrum CDMA signal at input **41** is despread by first mixer **51** as a first despread signal, using the first chip-code signal generated by first chip-code-signal generator **52**. The first despread signal from the first mixer **51** is filtered through first integrator **54**. First integrator **54** integrates for a time T_b, the time duration of a symbol such as a bit. At the same time, the first chip-code signal is delayed by time T by delay device **53**. The delay time T is approximately equal to the integration time T_b plus system or component delays. Systems or component delays are usually small, compared to integration time T_b.

The delayed version of the first chip-code signal is processed with the first despread signal from the output of the first integrator **54** using the first spreading mixer **55**. The output of the first spreading mixer **55** is fed to subtractors other than first subtractor **150** for processing the second through N^{th} channels of the spread-spectrum CDMA signal.

For reducing interference to the first channel of the spread-spectrum CDMA signal, the received spread-spectrum CDMA signal is processed by the second through N^{th} despreaders as follows. The second channel of the spread-spectrum CDMA signal is despread by the second despreading means. At the second mixer **61**, a second chip-code signal, generated by the second chip-code-signal generator **62**, despreads the second channel of the spread-spectrum CDMA signal. The despread second channel is filtered through second integrator **64**. The output of the second integrator **64** is the second despread signal. The second despread signal is spread-spectrum processed by second processing mixer **65** by a delayed version of the second chip-code signal. The second chip-code signal is delayed through delay device **63**. The delay device **63** delays the second chip-code signal by time T. The second channel mixer **65** spread-spectrum processes a timed version, i.e. delayed version, of the second chip-code signal with the filtered version of the second spread-spectrum channel from second integrator **64**. The term "spread-spectrum process" as used herein includes any method for generating a spread-spectrum signal by mixing or modulating a signal with a chip-code signal. Spread-spectrum processing may be done by product devices, EXCLUSIVE-OR gates, matched filters, or any other device or circuit as is well known in the art.

Similarly, the N^{th} channel of the spread-spectrum CDMA signal is despread by the N^{th} despreading means. Accordingly, the received spread-spectrum CDMA signal has the N^{th} channel despread by N^{th} mixer **71**, by mixing the spread-spectrum CDMA signal with the N^{th} chip-code signal from N^{th} chip-code-signal generator **72**. The output of the N^{th} mixer **71** is filtered by N^{th} integrator **74**. The output of

the N^{th} integrator **74**, which is the N^{th} despread signal, is a despread and filtered version of the N^{th} channel of the spread-spectrum CDMA signal. The N^{th} despread signal is spread-spectrum processed by a delayed version of the N^{th} chip-code signal. The N^{th} chip-code signal is delayed through N^{th} delay device **73**. The N^{th} processing mixer **75** spread-spectrum processes the timed version, i.e. a delayed version, of the N^{th} chip-code signal with the N^{th} despread signal.

At the first subtractor **150**, each of the outputs of the second processing mixer **65** through the N^{th} processing mixer **75** is subtracted from a timed version, i.e. a delayed version, of the spread-spectrum CDMA signal from input **41**. The delay of the spread-spectrum CDMA signal is timed through the first main delay device **48**. Typically, the delay of the first main delay device **48** is time T, which is approximately equal to the integration time of the first integrator **54** through N^{th} integrator **74**.

At the output of the first subtractor **150**, is generated a first subtracted signal. The first subtracted signal, for the first channel of the spread-spectrum CDMA signal, is defined herein to be the outputs from the second processing mixer **65** through N^{th} processing mixer **75**, subtracted from the delayed version of the spread-spectrum CDMA signal. The second subtracted signal through N^{th} subtracted signal are similarly defined.

The delayed version of the first chip-code signal from the output of first delay device **53** is used to despread the output of the first subtractor **150**. Accordingly, the first subtracted signal is despread by the first chip-code signal by first channel mixer **147**. The output of the first channel mixer **147** is filtered by first channel integrator **147**. This produces an output estimate d_1 of the first channel of the spread-spectrum CDMA signal.

As illustratively shown in FIG. **2**, a plurality of subtractors **150**, **250**, **350**, **450** can be coupled appropriately to the input **41** and to a first spreading mixer **55**, second spreading mixer **65**, third spreading mixer, through an N^{th} spreading mixer **75** of FIG. **1**. The plurality of subtractors **150**, **250**, **350**, **450** also are coupled to the main delay device **48** from the input **41**. This arrangement can generate a first subtracted signal from the first subtractor **150**, a second subtracted signal from the second subtractor **250**, a third subtracted signal from the third subtractor **350**, through an N^{th} subtracted signal from an N^{th} subtractor **450**.

The outputs of the first subtractor **150**, second subtractor **250**, third subtractor **350**, through the N^{th} subtractor **450** are each coupled to a respective first channel mixer **147**, second channel mixer **247**, third channel mixer **347**, through N^{th} channel mixer **447**. Each of the channel mixers is coupled to a delayed version of the first chip-code signal, $g_1(t-T)$; second chip-code signal, $g_2(t-T)$, third chip-code signal, $g_3(t-T)$, through N^{th} chip-code signal, $g_N(t-T)$. The outputs of each of the respective first channel mixer **147**, second channel mixer **247**, third channel mixer **347**, through N^{th} channel mixer **447** are coupled to a first channel integrator **146**, second channel integrator **246**, third channel integrator **346** through N^{th} channel integrator **446**, respectively. At the output of each of the channel integrators is produced an estimate of the respective first channel d_1, second channel d_2, third channel d_3, through N^{th} channel d_N.

Referring to FIG. **1**, use of the present invention is illustrated for the first channel of the spread-spectrum CDMA signal, with the understanding that the second through N^{th} CDMA channels work similarly. A received spread-spectrum CDMA signal at input **41** is delayed by

delay device **48** and fed to the first subtractor **150**. The spread-spectrum CDMA signal has the second channel through N^{th} channel despread by second mixer **61** using the second chip-code signal, through the N^{th} mixer **71** using the N^{th} chip-code signal. The respective second chip-code signal through the N^{th} chip-code signal are generated by the second chip-code-signal generator **62** through the N^{th} chip-code-signal generator **72**. The second channel through N^{th} channel are despread and filtered through the second integrator **64** through the N^{th} integrator **74**, respectively. The despreading removes, partially or totally, the non-despread channels at the outputs of each of the second integrator **64** through N^{th} integrator **74**.

In a preferred embodiment, each of the chip-code signal used for the first chip-code-signal generator **52**, second chip-code-signal generator **62** through the N^{th} chip-code-signal generator **72**, are orthogonal to each other. Use of chip-code signals having orthogonality however, is not required for operation of the present invention. When using orthogonal chip-code signals, the despread signals have the respective channel plus noise at the output of each of the integrators. With orthogonal chip-code signals, theoretically the mixers remove channels orthogonal to the despread channel. The respective channel is spread-spectrum processed by the respective processing mixer.

At the output of the second processing mixer **65** through the N^{th} processing mixer **75** is a respread version of the second channel through the N^{th} channel, plus noise components contained therein. Each of the second channel through N^{th} channel is then subtracted from the received spread-spectrum CDMA signal by the first subtractor **150**. The first subtractor **150** produces the first subtracted signal. The first subtracted signal is despread by a delayed version of the first chip-code signal by first channel mixer **147**, and filtered by first channel filter **146**. Accordingly, prior to despreading the first channel of the spread-spectrum CDMA signal, the second through N^{th} channels plus noise components aligned with these channels are subtracted from the received spread-spectrum CDMA signal. As illustratively shown in FIG. **3**, an alternative embodiment of the spread-spectrum CDMA interference canceler includes a plurality of first despreading means, a plurality of spread-spectrum-processing means, subtracting means, and second despreading means. In FIG. **3**, the plurality of despreading means is shown as first despreading means, second despreading means through N^{th} despreading means. The first despreading means is embodied as a first matched filter **154**. The first matched filter **154** has an impulse response matched to the first chip-code signal, which is used to spread-spectrum process and define the first channel of the spread-spectrum CDMA signal. The first matched filter **154** is coupled to the input **41**.

The second despreading means is shown as second matched filter **164**. The second matched filter **164** has an impulse response matched to the second chip-code signal, which is used to spread-spectrum process and define the second channel of the spread-spectrum CDMA signal. The second matched filter **164** is coupled to the input **41**.

The N^{th} despreading means is shown an N^{th} matched filter **174**. The N^{th} matched filter has an impulse response matched to the N^{th} chip-code signal, which is used to spread-spectrum process and define the N^{th} channel of the spread-spectrum CDMA signal. The N^{th} matched filter is coupled to the input **41**.

The term matched filter, as used herein, includes any type of matched filter that can be matched to a chip-code signal. The matched filter may be a digital matched filter or analog matched filter. A surface acoustic wave (SAW) device may be used at a radio frequency (RF) or intermediate frequency (IF). Digital signal processors and application specific integrated circuits (ASIC) having matched filters may be used at RF, IF or baseband frequency.

In FIG. **3**, the plurality of spread-spectrum-processing means is shown as the first processing mixer **55**, the second processing mixer **65**, through the N^{th} processing mixer **75**. The first processing mixer **55** may be coupled through a first adjustment device **97** to the first chip-code-signal generator **52**. The second processing mixer **65** may be coupled through the second adjustment device **98** to the second chip-code-signal generator **62**. The N^{th} processing mixer **75** may be coupled through the N^{th} adjustment device **73** to the N^{th} chip-code-signal generator **72**. The first adjustment device **97**, second adjustment device **98** through N^{th} adjustment device **99** are optional, and are used as an adjustment for aligning the first chip-code signal, second chip-code signal through N^{th} chip-code signal with the first despread signal, second despread signal through N^{th} despread signal, outputted from the first matched filter **154**, second matched filter **164** through N^{th} matched filter **174**, respectively.

The subtracting means is shown as the first subtractor **150**. The first subtractor **150** is coupled to the output of the second processing mixer **65**, through the N^{th} processing mixer **75**. Additionally, the first subtractor **150** is coupled through the main delay device **48** to the input **41**.

The first channel-despreading means is shown as a first channel-matched filter **126**. The first channel-matched filter **126** is coupled to the first subtractor **150**. The first channel-matched filter **126** has an impulse response matched to the first chip-code signal.

A first channel of a received spread-spectrum CDMA signal, at input **41**, is despread by first matched filter **154**. The first matched filter **154** has an impulse response matched to the first chip-code signal. The first chip-code signal defines the first channel of the spread-spectrum CDMA signal, and is used by the first chip-code-signal generator **52**. The first chip-code signal may be delayed by adjustment time τ by adjustment device **97**. The output of the first matched filter **154** is spread-spectrum processed by the first processing mixer **55** with the first chip-code signal. The output of the first processing mixer **55** is fed to subtractors other than the first subtractor **150** for processing the second channel through N^{th} channel of the spread-spectrum CDMA signals.

For reducing interference to the first spread-spectrum channel, the received spread-spectrum CDMA signal is processed by the second despreading means through N^{th} despreading means as follows. The second matched filter **164** has an impulse response matched to the second chip-code signal. The second chip-code signal defines the second channel of the spread-spectrum CDMA signal, and is used by the second chip-code-signal generator **62**. The second matched filter **164** despreads the second channel of the spread-spectrum CDMA signal. The output of the second matched filter **164** is the second despread signal. The second despread signal triggers second chip-code-signal generator **62**. The second despread signal also is spread-spectrum processed by second processing mixer **65** by a timed version of the second chip-code signal. The timing of the second chip-code signal triggers the second despread signal from the second matched filter **164**.

Similarly, the N^{th} channel of the spread-spectrum CDMA signal is despread by the N^{th} despreading means. Accordingly, the received spread-spectrum CDMA signal has the

N^{th} channel despread by N^{th} matched filter **174**. The output of the N^{th} matched filter **174** is the N^{th} despread signal, i.e. a despread and filtered version of the N^{th} channel of the spread-spectrum CDMA signal. The N^{th} despread signal is spread-spectrum processed by a timed version of the N^{th} chip-code signal. The timing of the N^{th} chip-code signal is triggered by the N^{th} despread signal from the N^{th} matched filter **174**. The N^{th} processing mixer **75** spread-spectrum processes the timed version of the N^{th} chip-code signal with the N^{th} despread signal.

At the first subtractor **150**, each of the outputs of the second processing mixer **65** through the N^{th} processing mixer **75** are subtracted from a delayed version of the spread-spectrum CDMA signal from input **41**. The delay of the spread-spectrum CDMA signal is timed through delay device **48**. The time of delay device **48** is set to align the second through N^{th} spread-spectrum-processed-despread signals for subtraction from the spread-spectrum CDMA signal. This generates at the output of the first subtractor **150**, a first subtracted signal. The subtracted signal is despread by the first channel-matched filter **126**. This produces an output estimate d_1 of the first channel of the spread-spectrum CDMA signal.

As illustrated in FIG. **4**, a plurality of subtractors **150**, **250**, **350**, **450** can be coupled appropriately to the output from a first processing mixer, second processing mixer, third processing mixer, through a N^{th} processing mixer, and to a main delay device from the input. A first subtracted signal is outputted from the first subtractor **150**, a second subtracted signal is outputted from the second subtractor **250**, a third subtracted signal is outputted from the third subtractor **350**, through an N^{th} subtractor signal is outputted from an N^{th} subtractor **450**.

The output of the first subtractor **150**, second subtractor **250**, third subtractor **350**, through the N^{th} subtractor **450** are each coupled to a respective first channel-matched filter **126**, second channel-matched filter **226**, third channel-matched filter **326**, through N^{th} channel-matched filter **426**. The first channel-matched filter **126**, second channel-matched filter **226**, third channel-matched filter **326** through N^{th} channel-matched filter **426** have an impulse response matched the first chip-code signal, second chip-code signal, third chip-code signal, through N^{th} chip-code signal, defining the first channel, second channel, third channel through N^{th} channel, respectively, of the spread-spectrum CDMA signal. At each of the outputs of the respective first channel-matched filter **126**, second channel-matched filter **226**, third channel-matched filter **326**, through N^{th} channel-matched filter **426**, is produced an estimate of the respective first channel d_1, second channel d_2, third channel d_3, through N^{th} channel d_n.

In use, the present invention is illustrated for the first channel of the spread-spectrum CDMA signal, with the understanding that the second channel through N^{th} channel work similarly. A received spread-spectrum CDMA signal at input **41** is delayed by delay device **48** and fed to subtractor **150**. The same spread-spectrum CDMA signal has the second through N^{th} channel despread by the second matched filter **164** through the N^{th} matched filter **174**. This despreading removes the other CDMA channels from the respective despread channel. In a preferred embodiment, each of the chip-code signals used for the first channel, second channel, through the N^{th} channel, is orthogonal to the other chip-code signals. At the output of the first matched filter **154**, second matched filter **164** through N^{th} matched filter **174**, are the first despread signal, second despread signal through N^{th} despread signal, plus noise.

The respective channel is spread-spectrum processed by the processing mixers. Accordingly, at the output of the

second processing mixer **65** through the N^{th} processing mixer **75** is a spread version of the second despread signal through the N^{th} despread signal, plus noise components contained therein. Each of the spread-spectrum-processed-despread signals, is then subtracted from the received spread-spectrum CDMA signal by the first subtractor **150**. This produces the first subtracted signal.

The first subtracted signal is despread by first channel-matched filter **126**. Accordingly, prior to despreading the first channel of the spread-spectrum CDMA signal, the second channel through N^{th} channel plus noise components aligned with these channels, are subtracted from the received spread-spectrum CDMA signal.

As is well known in the art, correlators and matched filters may be interchanged to accomplish the same function. FIGS. **1** and **3** show alternate embodiments using correlators or matched filters. The arrangements may be varied. For example, the plurality of despreading means may be embodied as a plurality of matched filters, while the channel despreading means may be embodied as a correlator. Alternatively, the plurality of despreading means may be a combination of matched filters and correlators. Also, the spread-spectrum-processing means may be embodied as a matched filter or SAW, or as EXCLUSIVE-OR gates or other devices for mixing a despread signal with a chip-code signal. As is well known in the art, any spread-spectrum despreader or demodulator may despread the spread-spectrum CDMA signal. The particular circuits shown in FIGS. **1–4** illustrate the invention by way of example.

The concepts taught in FIGS. **1–4** may be repeated, as shown in FIG. **5**. FIG. **5** illustrates a first plurality of interference cancelers **511**, **512**, **513**, a second plurality of interference cancelers **521**, **522**, **523**, through an N^{th} plurality of interference cancelers **531**, **532**, **533**. Each plurality of interference cancelers includes appropriate elements as already disclosed, and referring to FIGS. **1–4**. The input is delayed through a delay device in each interference canceler.

The received spread-spectrum CDMA signal has interference canceled initially by the first plurality of interference cancelers **511**, **512**, **513**, thereby producing a first set of estimates, i.e. a first estimate d_{11}, a second estimate d_{12}, through an N^{th} estimate d_{1N}, of the first channel, second channel through the N^{th} channel, of the spread-spectrum CDMA signal. The first set of estimates can have interference canceled by the second plurality of interference cancelers **521**, **522**, **523**. The first set of estimates $d_{11}, d_{12}, \ldots, d_{1N}$, of the first channel, second channel through N^{th} channel, are input to the second plurality of interference cancelers, interference canceler **521**, interference canceler **522** through N^{th} interference canceler **523** of the second plurality of interference cancelers. The second plurality of interference cancelers thereby produce a second set of estimates, i.e. $d_{21}, d_{22}, \ldots, d_{2N}$, of the first channel, second channel, through N^{th} channel. Similarly, the second set estimates can pass through a third plurality of interference cancelers, and ultimately through an M^{th} set of interference cancelers **531**, **532**, **533**, respectively.

The present invention also includes a method for reducing interference in a spread-spectrum CDMA receiver having N chip-code channels. Each of the N channels is identified by a distinct chip-code signal. The method comprises the steps of despreading, using a plurality of chip-code signals, the spread-spectrum CDMA signal as a plurality of despread signals, respectively. Using a timed version of the plurality of chip-code signals, the plurality of despread signals are spread-spectrum processed with a chip-code signal corre-

sponding to a respective despread signal. Each of the N–1 spread-spectrum-processed-despread signals, is subtracted from the spread-spectrum CDMA signal, with the N–1 spread-spectrum-processed-despread signals not including a spread-spectrum-processed signal of the i^{th} despread signal, thereby generating a subtracted signal. The subtracted signal is despread to generate the i^{th} channel.

The probability of error P_e for direct sequence, spread-spectrum CDMA system is:

$$P_e = \tfrac{1}{2}\,\mathrm{erfc}(\alpha SNR)^{1/2}$$

where erfc is complementary error function, SNR is signal-to-noise ratio, and $1 \leqq \alpha \leqq 2$. The value of α depends on how a particular interference canceler system is designed.

The SNR after interference cancellation and method is given by:

$$SNR = \frac{(PG/N)^{R+1}}{1 + (PG/N)^{R+1}\dfrac{1}{E_b/\eta}\,\dfrac{1-(N/PG)^{R+1}}{1-N/PG}}$$

where N is the number of channels, PG is the processing gain, R is the number of repetitions of the interference canceler, E_b is energy per information bit and η is noise power spectral density.

FIG. **6** illustrates theoretical performance characteristic, of the interference canceler and method for when $E_b/\eta=6$ dB. The performance characteristic is illustrated for SNR out of the interference canceler, versus PG/N. The lowest curve, for R=0, is the performance without the interference canceler. The curves, for R=1 and R=2, illustrates improved performance for using one and two iterations of the interference canceler as shown in FIG. **5**. As PG/N→1, there is insufficient SNR to operate. If PG>N, then the output SNR from the interference canceler approaches E_b/η. Further, if $(N/PG)^{R+1} \ll 1$, then

$$SNR \to (E_b/\eta)(1-N/PG).$$

FIG. **7** illustrates the performance characteristic for when $E_b/\eta=10$ dB. FIG. **7** illustrates that three iterations of the interference canceler can yield a 4 dB improvement with PG/N=2.

FIG. **8** illustrates the performance characteristic for when $E_b/\eta=15$ dB. With this bit energy to noise ratio, two iterations of the interference canceler can yield 6 dB improvement for PG/N=2.

FIG. **9** illustrates the performance characteristic for when $E_b/\eta=20$ dB. With this bit energy to noise ratio, two iterations of the interference canceler can yield 6 dB improvement for PG/N=2. Similarly, FIGS. **10** and **11** shows that one iteration of the interference canceler can yield more than 10 dB improvement for PG/N=2.

The present invention may be extended to a plurality of interference cancelers. As shown in FIG. **12**, a received spread-spectrum signal, R(t), is despread and detected by CDMA/DS detector **611**. Each of the channels is represented as outputs $O_{01}, O_{02}, O_{03}, \ldots, O_{0m}$. Thus, each output is a despread, spread-spectrum channel from a received spread-spectrum signal, R(t).

Each of the outputs of the CDMA/DS detector **611** is passed through a plurality of interference cancelers **612**, **613**, . . . , **614**, which are serially connected. Each of the spread-spectrum channels passes through the interference canceling processes as discussed previously. The input to each interference canceler is attained by sampling and holding the output of the previous stage once per bit time.

For channel i, the first interference canceler samples the output of the CDMA/DS detector at time $t=T+\tau_i$. This value is held constant as the input until $t=2T+\tau_i$ at which point the next bit value is sample. Thus, the input waveforms to the interference canceler are estimates, $\hat{d}_i(t-\tau)$, of the original data waveform, $d_i(t-\tau_i)$, and the outputs are second estimates, $\hat{\hat{d}}_i(t-\tau_i)$. The M spread-spectrum channel outputs O_{0i}, i=1, 2, . . . , M, are passed through interference canceler **612** to produce a new corresponding set of channel outputs O_{1i}, i=1, 2, . . . , M.

As shown in FIG. **13**, the outputs of a particular spread-spectrum channel, which are at the output of each of the interference cancelers, may be combined. Accordingly, combiner **615** can combine the output of the first channel which is from CDMA/DS detector **611**, and the output O_{11} from the first interference canceler **612**, and the output O_{21} from the second interference canceler **613**, through the output O_{N1} from the N^{th} interference canceler **614**. Each output to be combined is of the corresponding bit. Therefore "s" bit time delays is inserted for each O_{s1}. The combined outputs are then passed through the decision device **616**. This can be done for each spread spectrum channel, and therefore designate the outputs of each of the combiners **615**, **617**, **619** as averaged outputs O_1 for channel one, averaged output O_2 for channel two, and averaged output O_M for channel M. Each of the averaged outputs are sequentially passed through decision device **616**, decision device **618**, and decision device **620**. Preferably, the averaged outputs have multiplying factor c_j which may vary according to a particular design. In a preferred embodiment, $c_j=\tfrac{1}{2}^j$. This allows the outputs of the various interference cancelers to be combined in a particular manner.

FIGS. **14–17** illustrate simulation performance characteristics for the arrangement of FIGS. **12** and **13**. FIGS. **14–17** are for asynchronous channel (relative time delays are uniformly distributed between 0 and bit time, T), processing gain of 100, all user have equal powers, and thermal signal to noise ratio ($E_b N$ of 30 dB). Length 8191 Gold codes are used for the PN sequences.

In FIG. **14**, performance characteristic of each of the output stages of FIG. **12** is shown. Thus, **S0** represents the BER performance at the output of CDMA/DS detector **611**, **S1** represents the BER performance at the output of interference canceler **612**, **S2** represents the BER performance at the output of interference canceler **613**, etc. No combining of the outputs of the interference cancelers are used in determining the performance characteristic shown in FIG. **14**. Instead, the performance characteristic is for repetitively using interference cancelers. As a guideline, in each of the subsequent figures the output for each characteristic of CDMA/DS detector **611** is shown in each figure.

FIG. **15** shows the performance characteristic when the output of subsequent interference cancelers are combined. This is shown for a particular channel. Thus, curve **S0** is the output of the CDMA/DS detector **611**. Curve **S1** represents the BER performance of the average of the outputs of CDMA/DS detector **611** and interference canceler **612**. Here $C_0=C_1=\tfrac{1}{2}$ $C_j=0$, j not equal to zero, one. Curve **S2** represents the BER performance of the average output of interference canceler **613** and interference canceler **612**. Curve **S2** is determined using the combiner shown in FIG. **13**. Here, C_1 and C_2 are set equal to ½ and all other C_j set to zero. Similarly, curve **S3** is the performance of the output of a second and third interference canceler averaged together. Thus, curve **S3** is the performance characteristic of the average between output of a second and third interference canceler. Curve **S4** is the performance characteristic of the

average output of a third and fourth interference canceler. Only two interference cancelers are taken at a time for determining a performance characteristic of an average output of those to particular interference cancelers.

FIG. 16 shows the regular outputs for the CDMA/DS detector 611, and a first and second interference canceler 612, 613. Additionally, the average output of the CDMA/DS detector 611 and the first interference canceler 612 is shown as S1 AVG. The BER performance of the average of the outputs of the first interference canceler 612 and the second interference canceler 613 is shown as the average output S2 AVG.

FIG. 17 shows performance characteristic correspondence for those of FIG. 16, but interms of signal to-noise ratio in decibels(dB).

It will be apparent to those skilled in the art that various modifications can be made to the spread-spectrum CDMA interference canceler and method of the instant invention without departing from the scope or spirit of the invention, and it is intended that the present invention cover modifications and variations of the spread-spectrum CDMA interference canceler and method provided they come within the scope of the appended claims and their equivalents.

We claim:

1. A spread-spectrum code division multiple access (CDMA) interference-canceler system for reducing interference in a spread-spectrum CDMA receiver having N channels, with each of the N channels identified by a distinct chip-code signal, comprising:

a plurality of interference cancelers, each of said plurality of interference cancelers including,

means for generating a plurality of chip-code signals;

means for despreading, using the plurality of chip-code signals, a spread-spectrum CDMA signal as a plurality of despread signals, respectively;

means for timing the plurality of chip-code signals to generate a plurality of timed chip-code signals;

means, responsive to the plurality of timed chip-code-signals, for spread-spectrum processing the plurality of despread signals with the plurality of timed chip-code-signals, respectively;

means, for an i^{th} chip-code signal, for subtracting from the spread-spectrum CDMA signal each of an N–1 plurality of spread-spectrum processed despread signals, with the N–1 plurality of spread-spectrum processed despread signals not including the i^{th} spread-spectrum processed despread signal of an i^{th} despread signal, thereby generating a subtracted signal; and

channel means for despreading the subtracted signal with the i^{th} timed chip-code signal as an i^{th} channel signal.

2. The spread-spectrum CDMA interference canceler system as set forth in claim 1 with said despreading means including:

a filter;

a chip-code generator for generating a chip-code signal from a respective chip codeword; and

a mixer coupled between said filter and said chip-code generator.

3. The spread-spectrum CDMA interference canceler system as set forth in claim 2 with said channel means including:

a filter;

a chip-code generator for generating a chip-code signal from a chip codeword corresponding to the i^{th} channel signal; and

a mixer coupled between said filter and said chip-code generator.

4. The spread-spectrum CDMA interference canceler system as set forth in claim 1 with said despreading means including a matched filter having an impulse response matched to a respective chip codeword.

5. The spread-spectrum CDMA interference canceler system as set forth in claim 4 with said channel means including:

a filter;

a chip-code generator for generating a chip-code signal from a chip codeword corresponding to the i^{th} channel signal; and

a mixer coupled between said filter and said chip-code generator.

6. The spread-spectrum CDMA interference canceler system as set forth in claim 4 with said channel means including a matched filter having an impulse response matched to a chip codeword corresponding to the i^{th} channel.

7. The spread-spectrum CDMA interference canceler system as set forth in claim 1 with said channel means including:

a filter;

a chip-code generator for generating a chip-code signal from a chip codeword corresponding to the i^{th} channel signal; and

a mixer coupled between said filter and said chip-code generator.

8. The spread-spectrum CDMA interference canceler system as set forth in claim 1 with said despreading means including a digital signal processor with digital matched filter having an impulse response matched to a respective chip codeword.

9. The spread-spectrum CDMA interference canceler system as set forth in claim 8 with said channel means including a matched filter having an impulse response matched to a chip codeword corresponding to the i^{th} channel.

10. The spread-spectrum CDMA interference canceler system as set forth in claim 8 with said channel means including a surface acoustic wave (SAW) device having an impulse response matched to a chip codeword corresponding to the i^{th} channel.

11. The spread-spectrum CDMA interference canceler system as set forth in claim 1 with said channel means including a digital signal processor with digital matched filter having an impulse response matched to a chip codeword corresponding to the i^{th} channel.

12. The spread-spectrum CDMA interference canceler system as set forth in claim 1 with said despreading means including a surface acoustic wave (SAW) device having an impulse response matched to a chip codeword corresponding to the i^{th} channel.

13. The spread-spectrum CDMA interference canceler system as set forth in claim 12 with said channel means including a matched filter having an impulse response matched to a chip codeword corresponding to the i^{th} channel.

14. The spread-spectrum CDMA interference canceler system as forth in claim 12 with said channel means including a chip-code generator for generating a chip-code signal from a digital matched filter having an impulse response matched to a chip codeword corresponding to the i^{th} channel.

15. The spread-spectrum CDMA interference canceler system forth in claim 12 with said channel means including a surface acoustic wave (SAW) device having an impulse

response matched to a chip codeword corresponding to the i^{th} channel.

16. A spread-spectrum code division multiple access (CDMA) interference-canceler system for reducing interference in a spread-spectrum CDMA receiver having N channels, with each of the N channels identified by a distinct chip-code signal, comprising:

a CDMA/DS detector for detecting and despreading a received spread-spectrum signal having a plurality of channels as a plurality of despread, spread-spectrum channels;

a plurality of serially connected interference cancelers each for processing the plurality of despread, spread-spectrum channels and for outputting a respective plurality of estimates of the plurality of channels; and and

a combiner for combining, using the outputs of the plurality of interference cancelers, a plurality of estimates of a particular channel to generate an averaged estimate.

17. A spread-spectrum code division multiple access (CDMA) interference-canceler system for reducing interference in a spread-spectrum CDMA receiver having N channels, with each of the N channels identified by a distinct chip-code signal, comprising:

a CDMA/DS detector for detecting and despreading a received spread-spectrum signal having a plurality of channels as a plurality of despread, spread-spectrum channels;

a plurality of serially connected interference cancelers each for processing the plurality of despread, spread-spectrum channels and for outputting a respective plurality of estimates of the plurality of channels;

means for combining, using the respective plurality of estimates from said plurality of interference cancelers, a first plurality of estimates for a first channel to generate a first averaged output for channel one, a second plurality of estimates for a second channel to generate a second averaged output for channel two, and an M^{th} plurality of estimates for an M^{th} channel to generate an M^{th} averaged output for channel M; and

decision means for processing the first averaged output for channel one, the second averaged output for channel two, and the M^{th} averaged output for channel M.

18. A method for reducing interference in a spread-spectrum code division multiple access (CDMA) receiver having N channels, with each of the N channels identified by a distinct chip-code signal, using a plurality of interference cancelers, each of said plurality of interference cancelers including a plurality of chip-code generators for generating a plurality of chip-code signals and a plurality of timed devices for generating a plurality of timed-chip-code signals, comprising the steps, within each of said plurality of interference cancelers, of:

a. despreading, simultaneously, a plurality of spread-spectrum channels of a spread-spectrum CDMA signal as a plurality of despread signals using the plurality of chip-code signals, respectively;

b. spread-spectrum processing, simultaneously, using the plurality of timed-chip-code-signals, the plurality of despread signals, respectively, with each of the plurality of timed-chip-code signals corresponding to a respective one of the plurality of despread signals;

c. subtracting from the spread-spectrum CDMA signal, each of a plurality of N−1 spread-spectrum-processed-despread signals, with the plurality of N−1 spread-spectrum-processed-despread signals not including a spread-spectrum processed despread signal of an i^{th} despread signal, thereby generating a subtracted signal;

d. despreading the subtracted signal with an i^{th} timed chip-code signal as an i^{th} channel signal, producing a first set of estimates of the N channels;

e. repeating steps a through d, using a second plurality of interference cancelers, producing a second set of estimates of the N channels; and

f. repeating steps a through d, using an M^{th} plurality of interference cancelers, producing an M^{th} set of estimates of the N channels.

19. A spread-spectrum code division multiple access (CDMA) interference-canceler system for reducing interference in a spread-spectrum CDMA receiver having N channels, with each of the N channels identified by a distinct chip-code signal, comprising:

a plurality of interference cancelers, each of said interference cancelers including,

a plurality of chip-code-signal generators for generating, simultaneously, a plurality of chip-code signals;

a plurality of correlators coupled to said plurality of chip-code generators through a plurality of mixers, each of said plurality of correlators responsive to a distinct chip-code signal of the plurality of chip-code-signals, for simultaneously despreading a plurality of spread-spectrum channels of a spread-spectrum CDMA signal as a plurality of despread signals, respectively;

a plurality of delay devices coupled to said plurality of chip-code-signal generators for delaying the plurality of chip-code signals as a timed plurality of chip-code signals, respectively;

a plurality of processing mixers coupled to said plurality of delay devices and to said plurality of correlators, responsive to the timed plurality of chip-code signals, for spread-spectrum processing, simultaneously, the plurality of despread signals, respectively, with a timed chip-code-signal corresponding to a respective despread signal, producing N spread-spectrum-processed-despread signals;

a plurality of subtractors, each of said plurality of subtractors for subtracting from the spread-spectrum CDMA signal all but a particular one of the N spread-spectrum-processed-despread signals, with the particular one of the N spread-spectrum-processed-despread signals being different for each of said plurality of subtractors, thereby generating a plurality of subtracted signals; and

a plurality of channel correlators for despreading the plurality of subtracted signals with a particular one of the plurality of timed chip-code signals, respectively, as a plurality of channel signals.

20. A spread-spectrum code division multiple access (CDMA) interference-canceler system for reducing interference in a spread-spectrum CDMA receiver having N channels, with each of the N channels identified by a distinct chip-code signal, comprising:

a CDMA/DS detector for detecting and despreading a received spread-spectrum signal having a plurality of channels as a plurality of despread, spread-spectrum channels;

a plurality of serially connected interference cancelers each for processing the plurality of despread, spread-spectrum channels and for outputting a respective plurality of estimates of the plurality of channels; and

means for combining, using the respective plurality of estimates from said plurality of interference cancelers, a first plurality of estimates for a first channel to generate a first averaged output for channel one, a second plurality of estimates for a second channel to generate a second averaged output for channel two, and an M^{th} plurality of estimates for an M^{th} channel to generate an M^{th} averaged output for channel M.

21. A spread-spectrum code division multiple access (CDMA) interference-canceler system for reducing interference in a spread-spectrum CDMA receiver having N channels, with each of the N channels identified by a distinct chip-code signal, comprising:

a plurality of serially connected interference cancelers each for processing a plurality of despread, spread-spectrum channels and for outputting a plurality of estimates of a plurality of spread-spectrum channels corresponding to the plurality of despread, spread-spectrum channels, respectively;

means for combining the plurality of estimates to produce a plurality of averaged estimates; and

decision means for processing the plurality of averaged estimates.

22. A spread-spectrum code division multiple access (CDMA) interference-canceler system for reducing interference in a spread-spectrum CDMA receiver having N channels, with each of the N channels identified by a distinct chip-code signal, comprising:

a plurality of serially connected interference cancelers each for processing a plurality of despread, spread-spectrum channels and for outputting a plurality of estimates of a plurality of spread-spectrum channels corresponding to the plurality of despread, spread-spectrum channels, respectively;

a plurality of combiners for combining the plurality of estimates to produce a plurality of averaged estimates; and

a plurality of decision devices for processing the plurality of averaged estimates.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,553,062

DATED : September 3, 1996

INVENTOR(S) : Donald L. Schilling and Shimon Moshavi

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 1, line 11: delete "data" and insert --date--; and after "1993," insert --now--.
Column 13, line 42: after "i^{th}" insert --timed--;
line 46: delete "the" and insert --an--; and
line 47: delete "of an i^{th} despread signal".
Column 15, line 15: delete the second appearance of "and".

Signed and Sealed this

Seventeenth Day of June, 1997

Attest:

Bruce Lehman

BRUCE LEHMAN

Attesting Officer *Commissioner of Patents and Trademarks*

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,553,062

DATED : Sept. 3, 1996

INVENTOR(S) : Donald L. Schilling, et al

It is certified that error appears in the above-indentified patent and that said Letters Patent is hereby corrected as shown below:

On the title page, item [73]

In the Assignee:

Delete "InterDigital Communications Corporation" and insert --InterDigital Technology Corporation--.

Signed and Sealed this

Fourth Day of November, 1997

Attest:

Bruce Lehman

BRUCE LEHMAN

Attesting Officer

Commissioner of Patents and Trademarks

US005719852A

United States Patent [19]

Schilling et al.

[11] Patent Number: 5,719,852

[45] Date of Patent: *Feb. 17, 1998

[54] SPREAD SPECTRUM CDMA SUBTRACTIVE INTERFERENCE CANCELER SYSTEM

[75] Inventors: Donald L. Schilling, Sands Point; John Kowalski; Shimon Moshavi, both of New York, all of N.Y.

[73] Assignee: InterDigital Technology Corporation, Wilmington, Del.

[*] Notice: The term of this patent shall not extend beyond the expiration date of Pat. No. 5,553,062.

[21] Appl. No.: 654,994

[22] Filed: May 29, 1996

Related U.S. Application Data

[63] Continuation of Ser. No. 279,477, Jul. 26, 1994, Pat. No. 5,553,062, which is a continuation-in-part of Ser. No. 51,017, Apr. 22, 1993, Pat. No. 5,363,403.

[51] Int. Cl.^{6} H04B 1/707; H04T 13/04

[52] U.S. Cl. 370/201; 370/333; 370/335; 370/342; 370/479; 375/206; 375/207; 375/208; 375/343; 375/346; 380/34

[58] Field of Search 370/464, 479, 370/310, 342, 201, 331, 332, 333, 335; 375/200, 205, 206, 207, 208, 209, 210, 343, 346; 380/34

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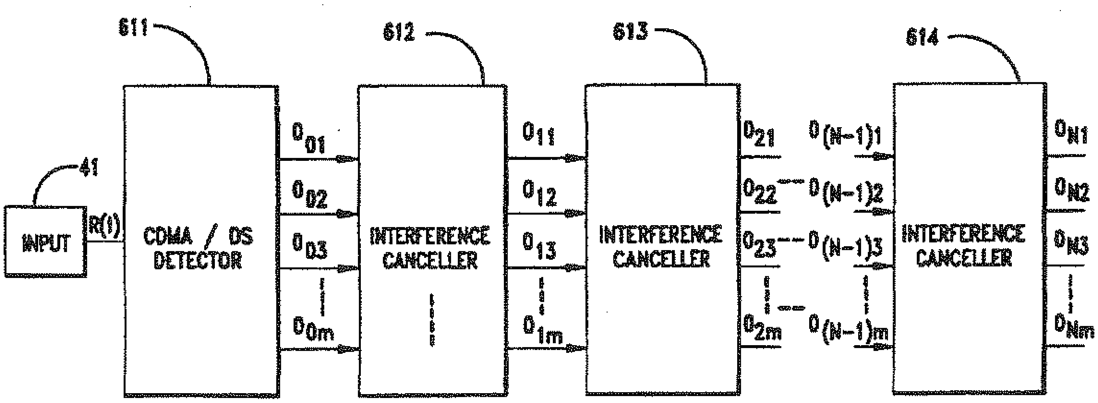
Primary Examiner—Alphus H. Hsu
Assistant Examiner—Seema S. Rao
Attorney, Agent, or Firm—David Newman & Associates, P.C.

[57] **ABSTRACT**

A spread-spectrum code division multiple access interference canceler for reducing interference in a direct sequence CDMA receiver having N chip-code channels. The interference canceler includes a plurality of correlators or matched filters, a plurality of spread-spectrum-processing circuits, subtracting circuits, and channel correlators or channel-matched filters. Using a plurality of chip-code signals, the plurality of correlators despreads the spread-spectrum CDMA signal as a plurality of despread signals, respectively. The plurality of spread-spectrum-processing circuits uses a timed version of the plurality of chip-code signals, for spread-spectrum processing the plurality of despread signals, respectively, with a chip-code-signal corresponding to a respective despread signal. For recovering a code channel using an i^{th} chip-code-signal, the subtracting circuits subtracts from the spread-spectrum CDMA signal, each of the N−1 spread-spectrum-processed-despread signals thereby generating a subtracted signal. The N−1 spread-spectrum-processed-despread signals do not include the spread-spectrum-processed-despread signal of the i^{th} channel of the spread-spectrum CDMA signal. The channel correlator or channel-matched filter despreads the subtracted signal.

12 Claims, 14 Drawing Sheets



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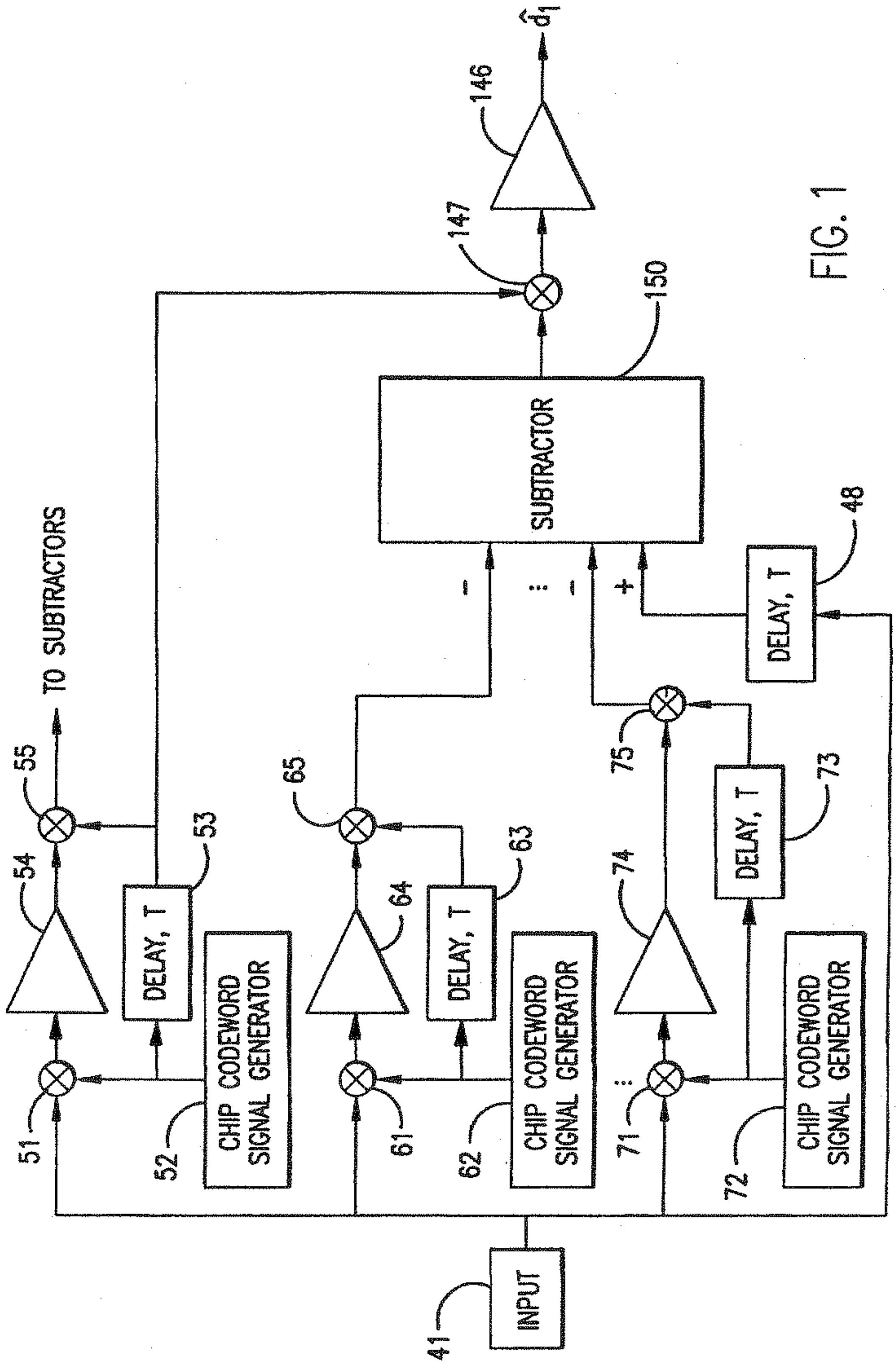
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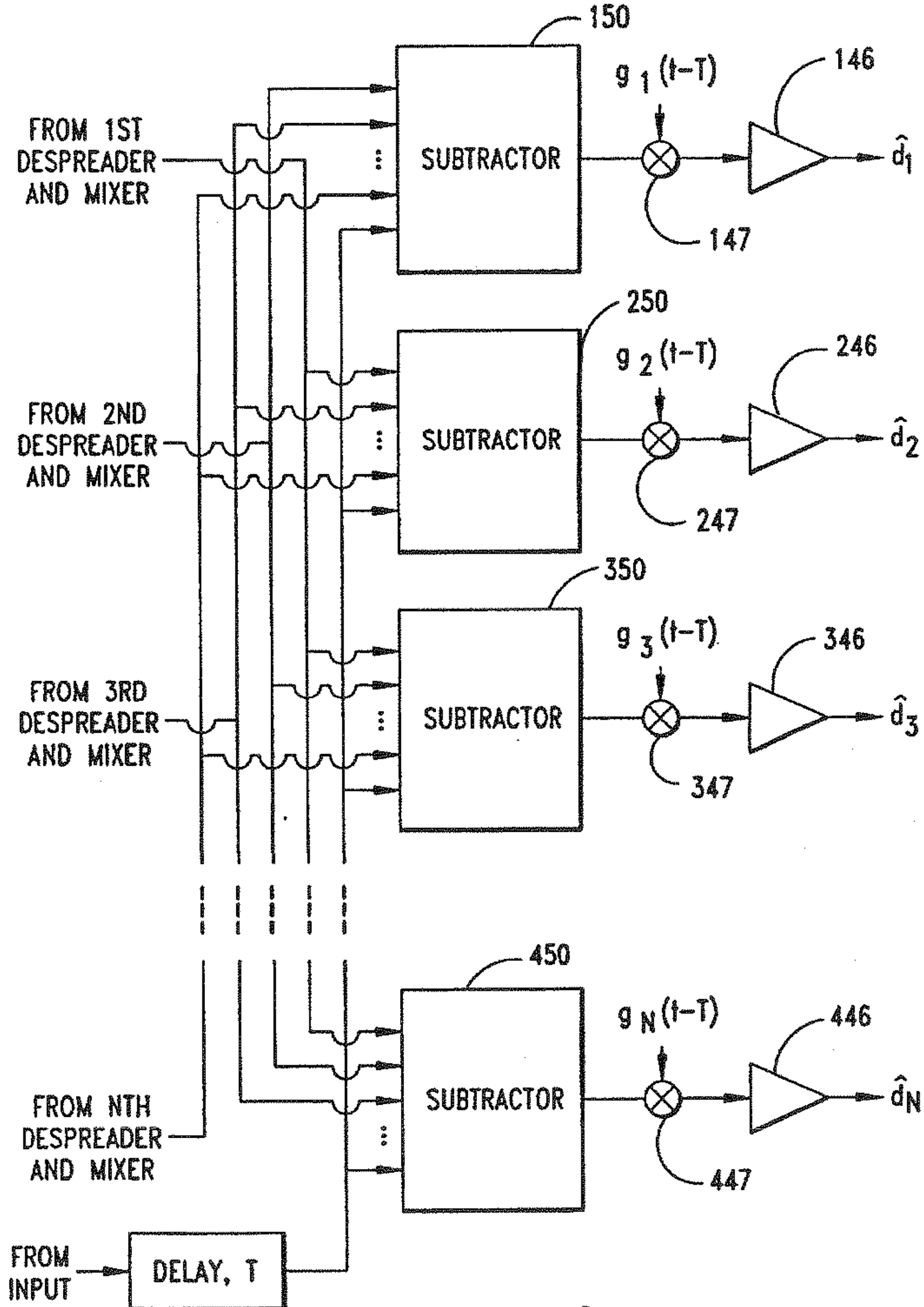
DELAY, T
CHIP CODEWORD SIGNAL GENERATOR
75
74
73
71
72
DELAY, T
CHIP CODEWORD SIGNAL GENERATOR
INPUT
41
DELAY, T
48
SUBTRACTOR
150
147
146
$\hat{d}_1$

FIG. 1



150
146
147
250
246
247
350
346
347
450
446
447
FROM 1ST DESPREADER AND MIXER
FROM 2ND DESPREADER AND MIXER
FROM 3RD DESPREADER AND MIXER
FROM NTH DESPREADER AND MIXER
SUBTRACTOR
SUBTRACTOR
SUBTRACTOR
SUBTRACTOR
$g_1(t-T)$
$g_2(t-T)$
$g_3(t-T)$
$g_N(t-T)$
$\hat{d}_1$
$\hat{d}_2$
$\hat{d}_3$
$\hat{d}_N$
FROM INPUT
DELAY, T

FIG. 2

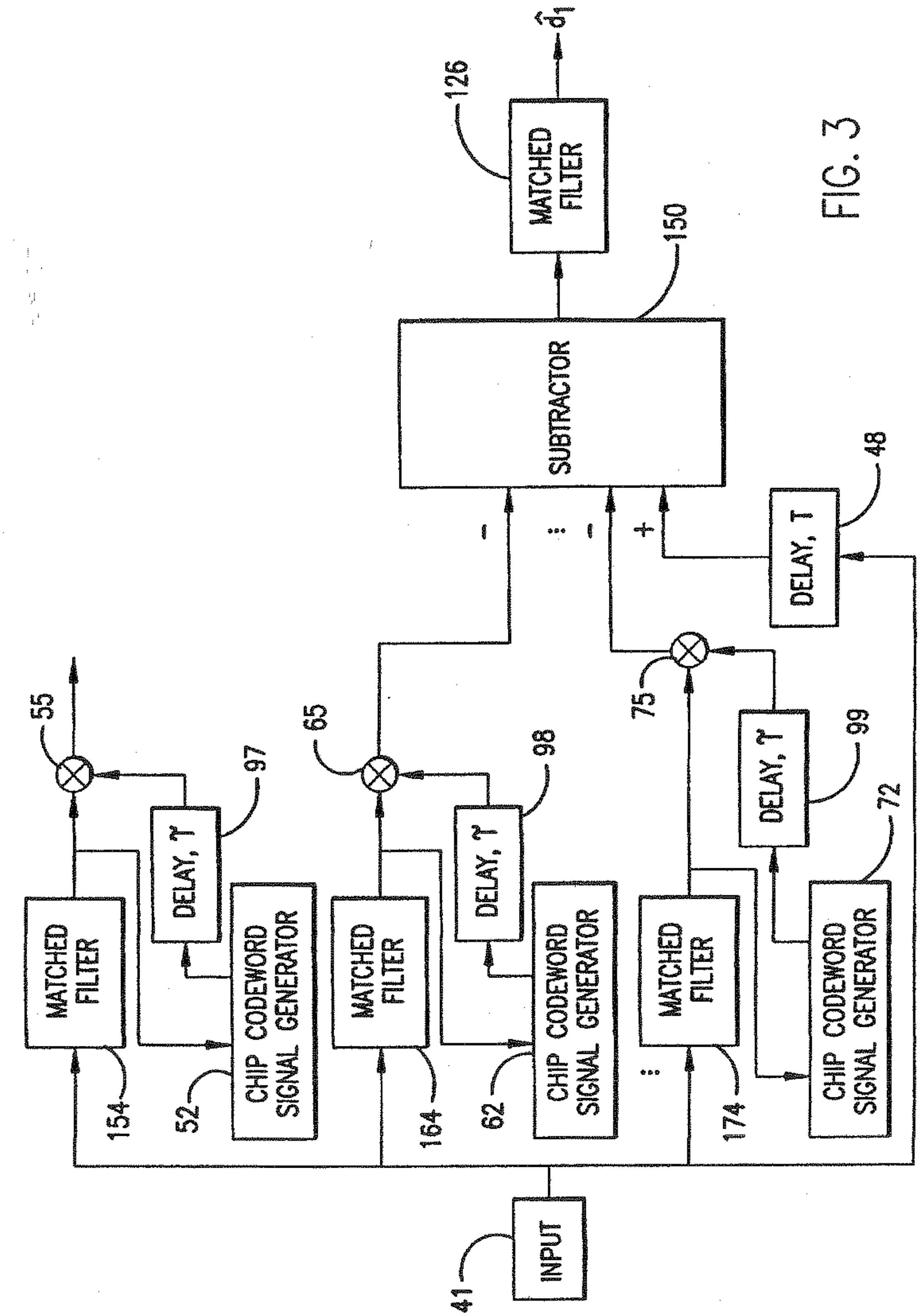

INPUT
41
MATCHED FILTER
154
MATCHED FILTER
164
MATCHED FILTER
174
CHIP CODEWORD SIGNAL GENERATOR
52
CHIP CODEWORD SIGNAL GENERATOR
62
CHIP CODEWORD SIGNAL GENERATOR
72
DELAY, τ
97
DELAY, τ
98
DELAY, τ
99
55
65
75
DELAY, T
48
SUBTRACTOR
150
MATCHED FILTER
126
$\hat{d}_1$

FIG. 3

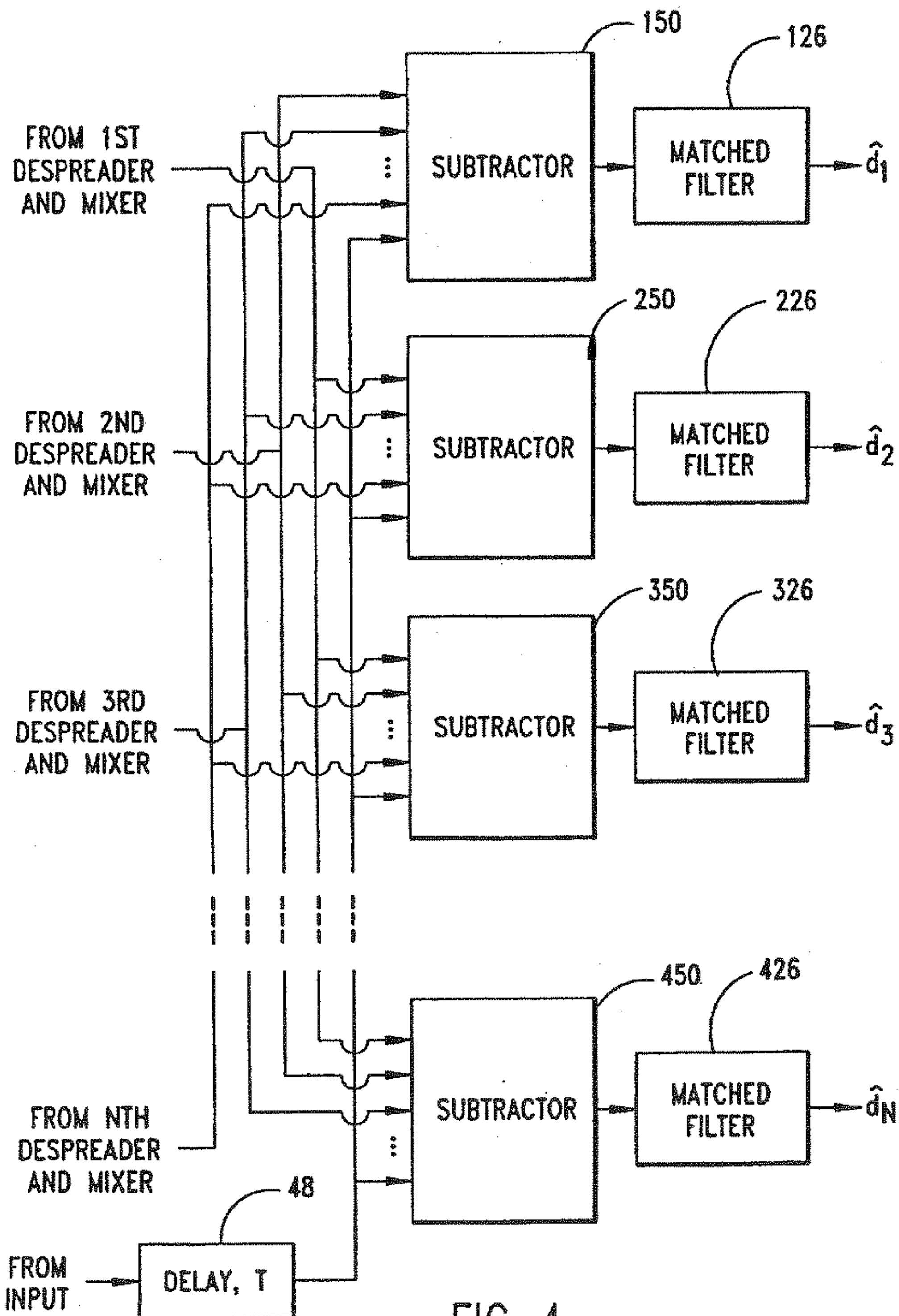

150
126
FROM 1ST DESPREADER AND MIXER
SUBTRACTOR
MATCHED FILTER
$\hat{d}_1$
250
226
FROM 2ND DESPREADER AND MIXER
SUBTRACTOR
MATCHED FILTER
$\hat{d}_2$
350
326
FROM 3RD DESPREADER AND MIXER
SUBTRACTOR
MATCHED FILTER
$\hat{d}_3$
450
426
FROM NTH DESPREADER AND MIXER
SUBTRACTOR
MATCHED FILTER
$\hat{d}_N$
48
FROM INPUT
DELAY, T

FIG. 4

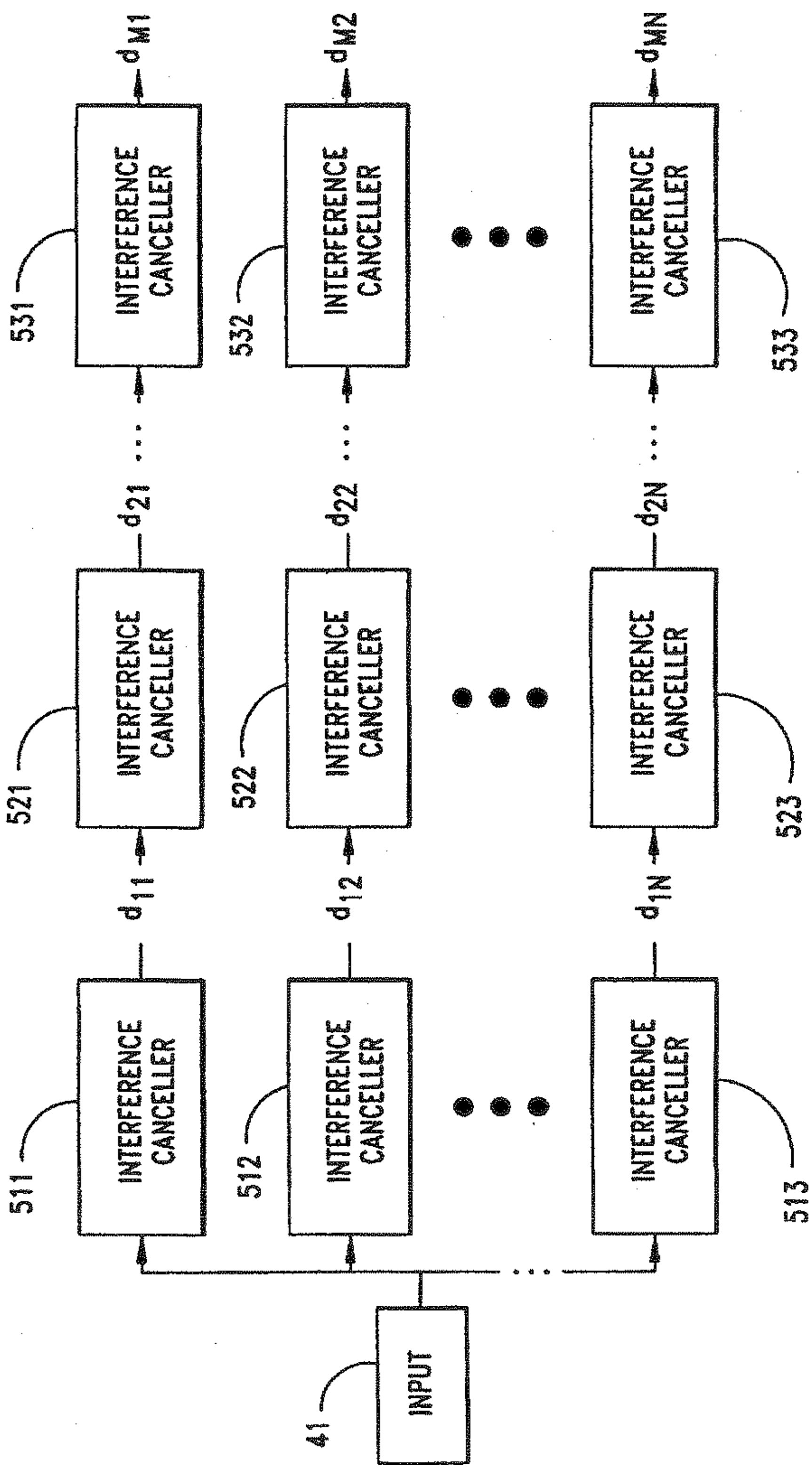
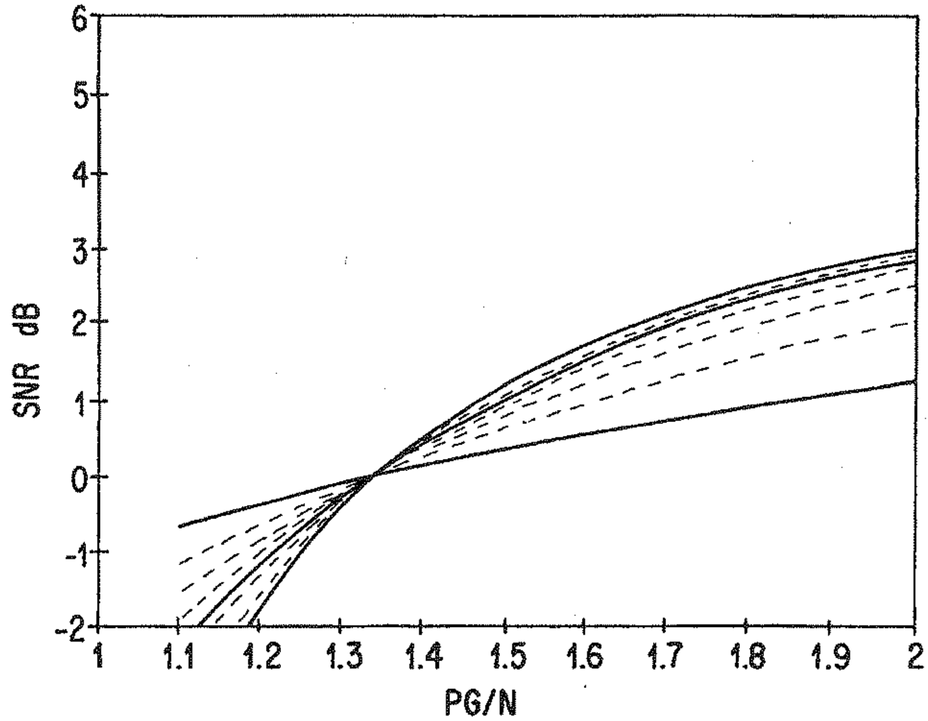
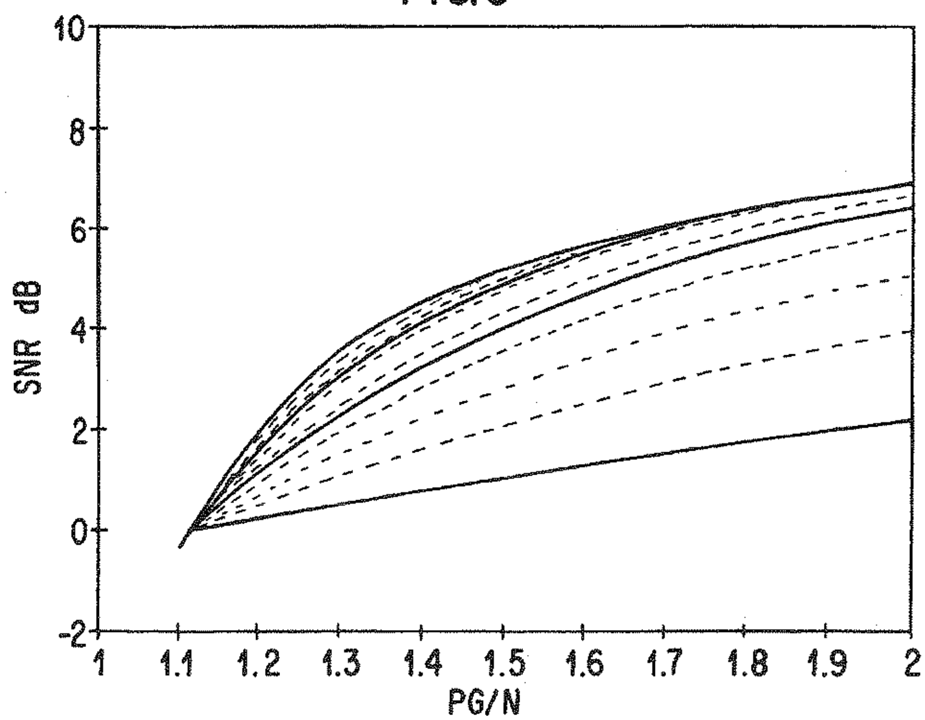

41
INPUT
511
INTERFERENCE CANCELLER
512
INTERFERENCE CANCELLER
513
INTERFERENCE CANCELLER
d_{11}
d_{12}
d_{1N}
521
INTERFERENCE CANCELLER
522
INTERFERENCE CANCELLER
523
INTERFERENCE CANCELLER
d_{21}
d_{22}
d_{2N}
531
INTERFERENCE CANCELLER
532
INTERFERENCE CANCELLER
533
INTERFERENCE CANCELLER
d_{M1}
d_{M2}
d_{MN}

FIG. 5



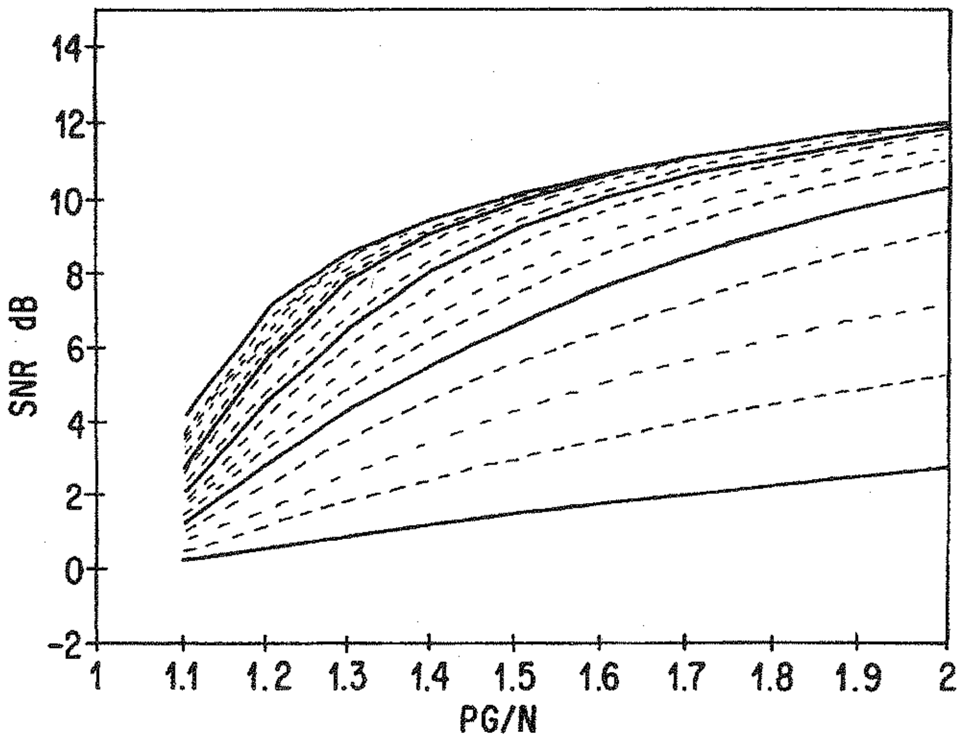
6
5
4
3
2
1
0
-1
-2
SNR dB
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

FIG.6



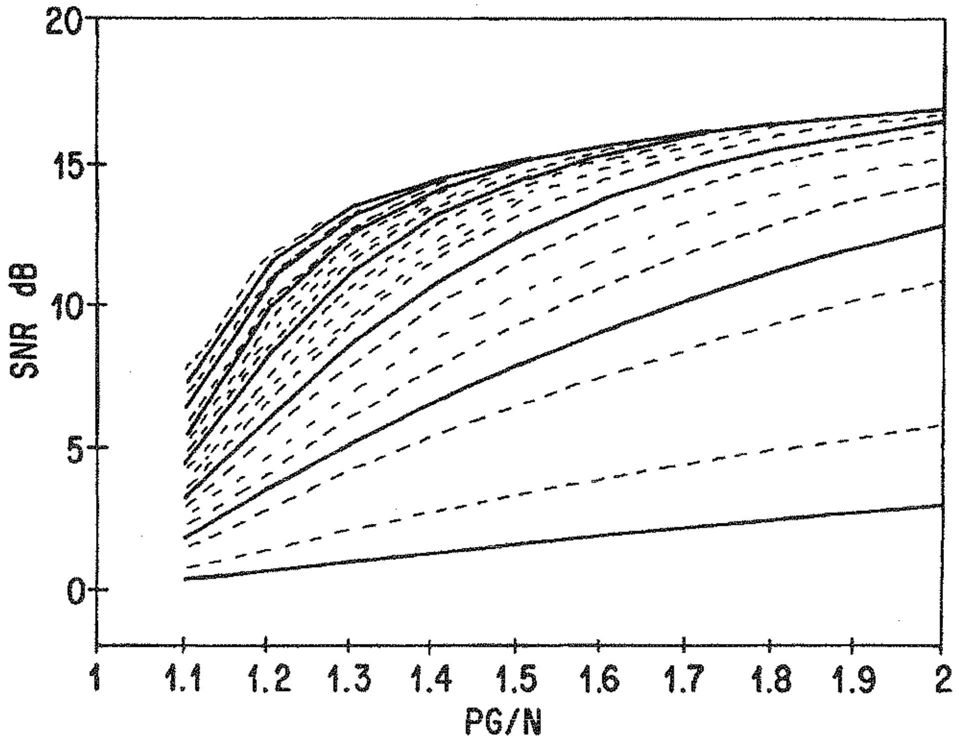
10
8
6
4
2
0
-2
SNR dB
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

FIG.7



SNR dB
14
12
10
8
6
4
2
0
-2
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

FIG. 8



SNR dB
20
15
10
5
0
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

FIG. 9

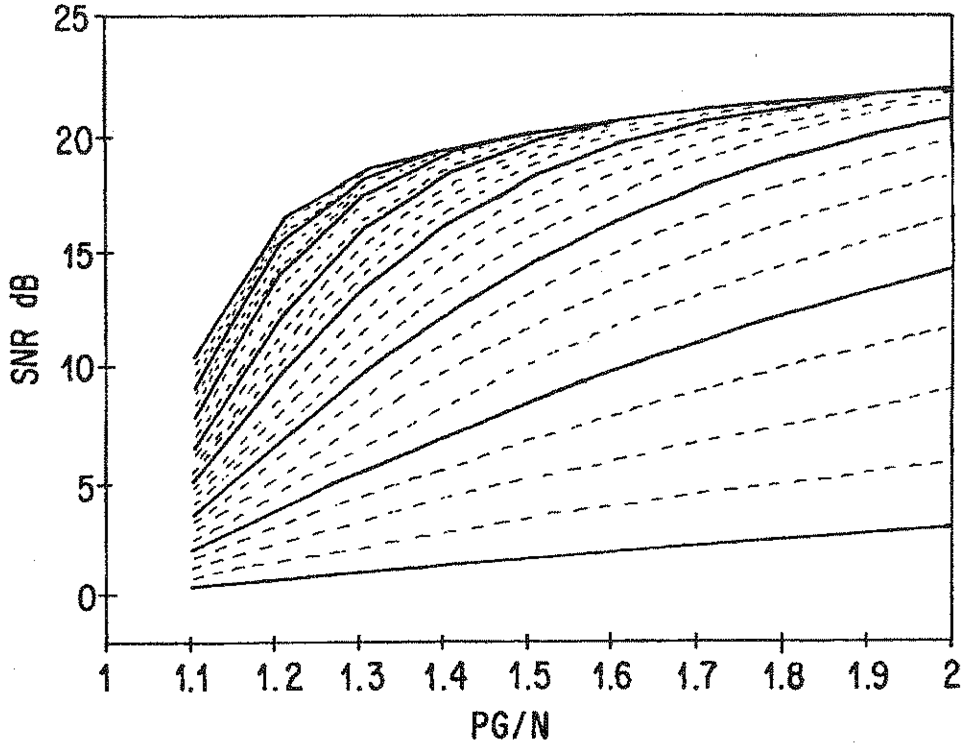

25
20
15
10
5
0
SNR dB
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

FIG.10

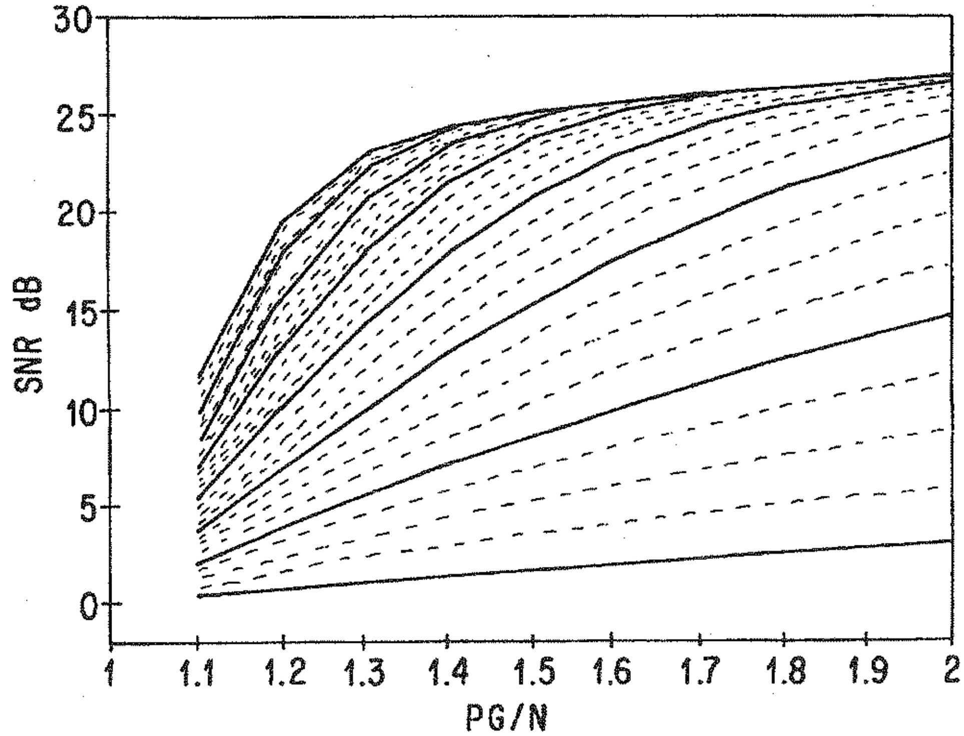

30
25
20
15
10
5
0
SNR dB
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

FIG.11

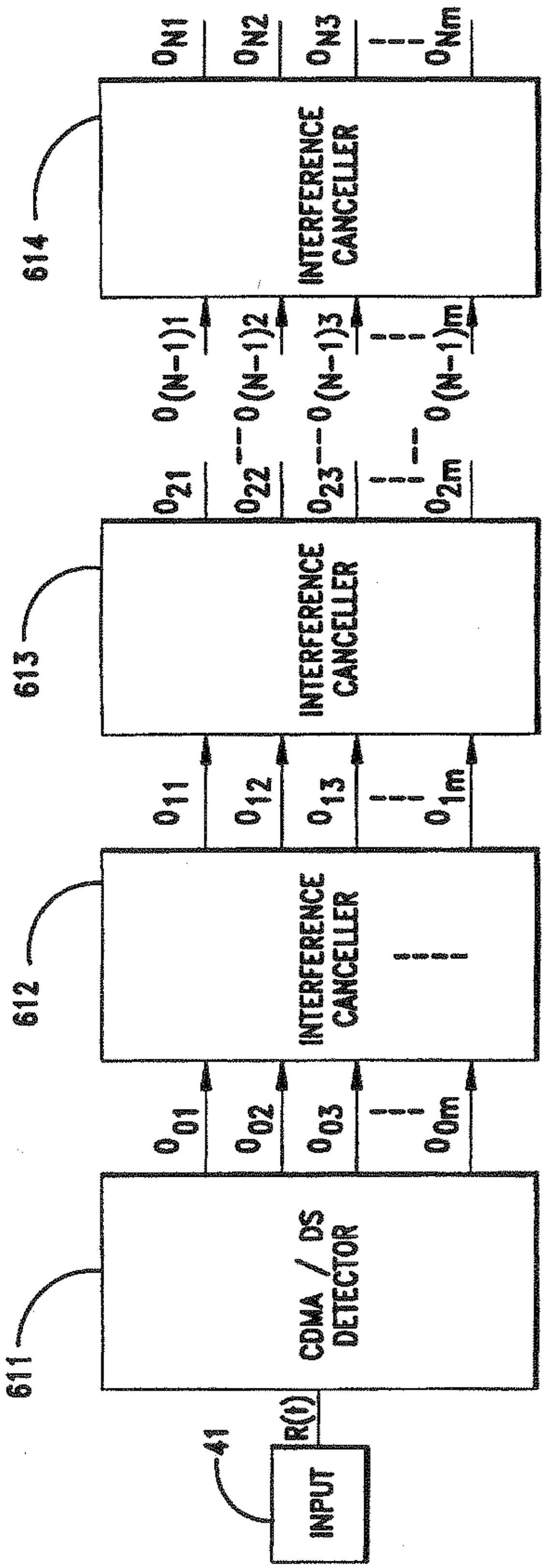

INPUT
41
R(t)
CDMA / DS DETECTOR
611
O_{01}
O_{02}
O_{03}
O_{0m}
INTERFERENCE CANCELLER
612
O_{11}
O_{12}
O_{13}
O_{1m}
INTERFERENCE CANCELLER
613
O_{21}
O_{22}
O_{23}
O_{2m}
$O_{(N-1)1}$
$O_{(N-1)2}$
$O_{(N-1)3}$
$O_{(N-1)m}$
INTERFERENCE CANCELLER
614
O_{N1}
O_{N2}
O_{N3}
O_{Nm}

FIG. 12

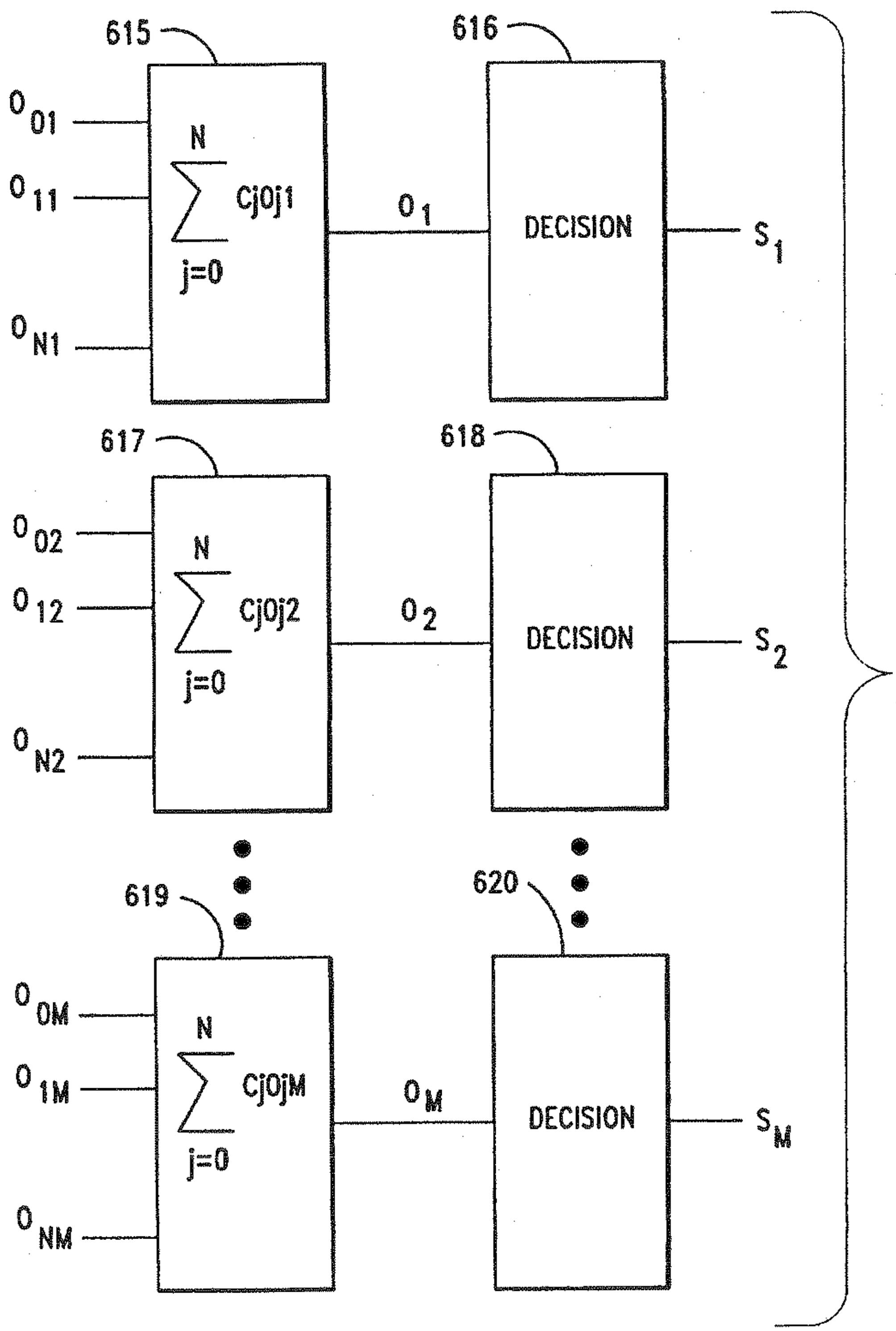

615
616
O 01
O 11
O N1
N
Cj0j1
j=0
O 1
DECISION
S 1
617
618
O 02
O 12
O N2
N
Cj0j2
j=0
O 2
DECISION
S 2
619
620
O 0M
O 1M
O NM
N
Cj0jM
j=0
O M
DECISION
S M

FIG. 13

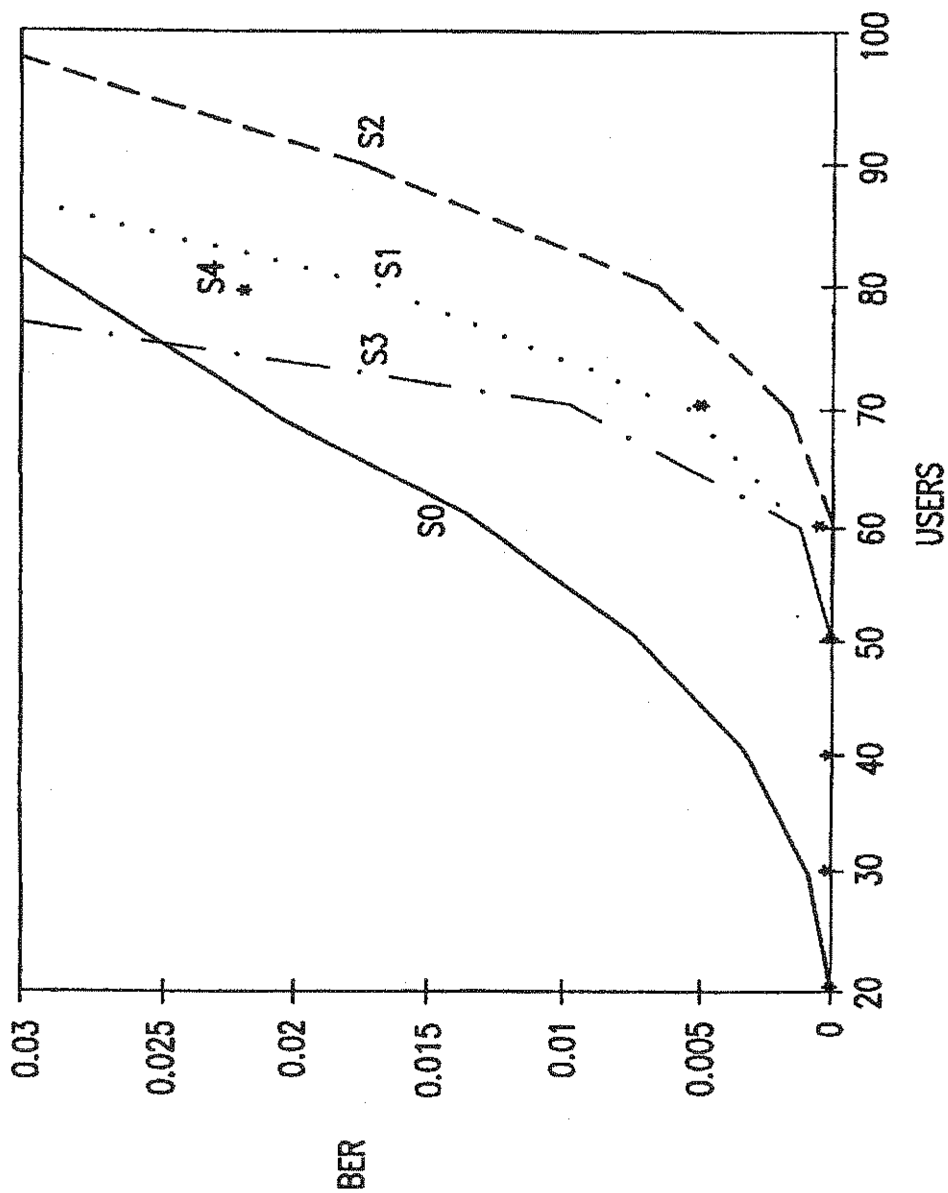

BER
0.03
0.025
0.02
0.015
0.01
0.005
0
USERS
20
30
40
50
60
70
80
90
100
S0
S1
S2
S3
S4

FIG. 14

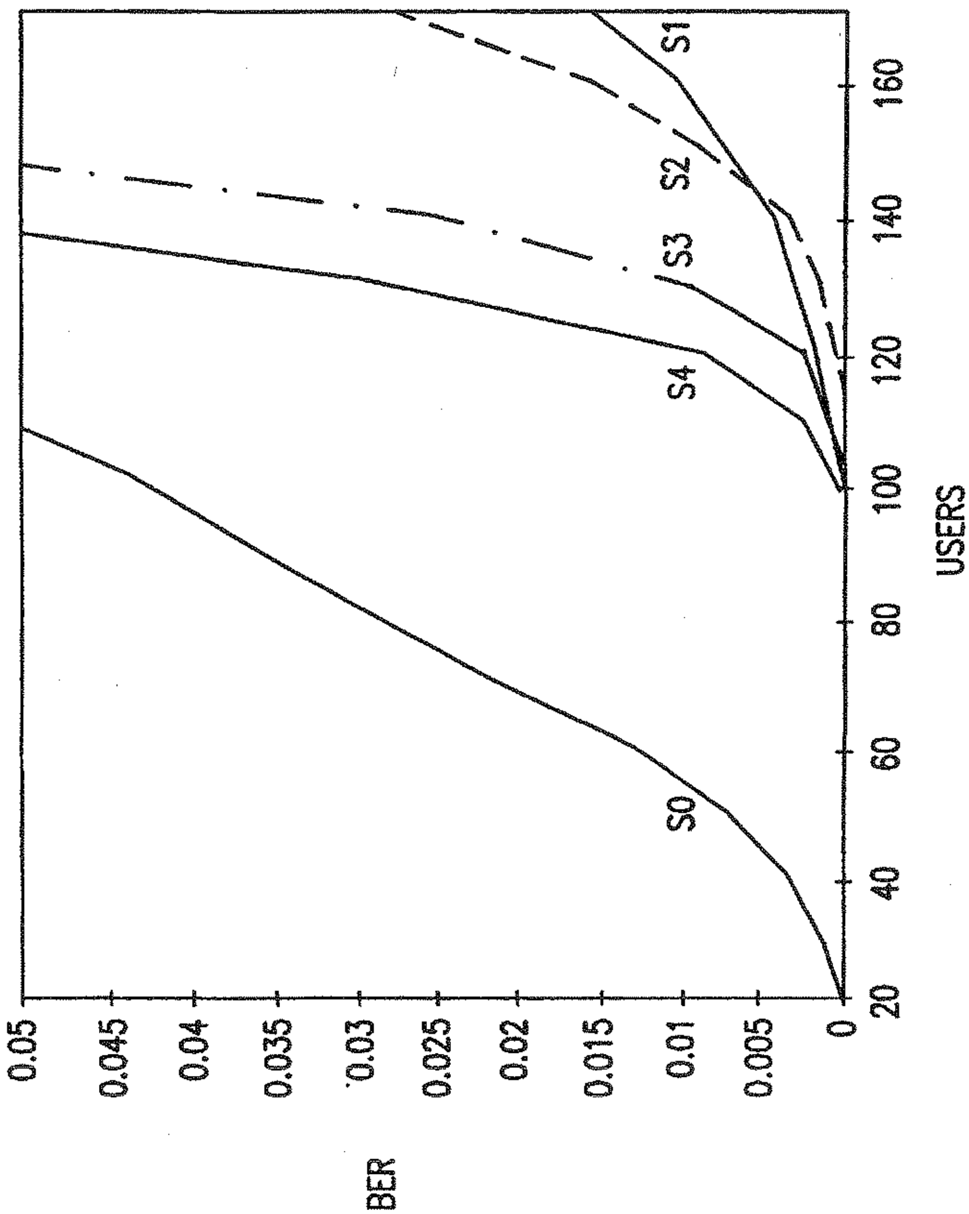
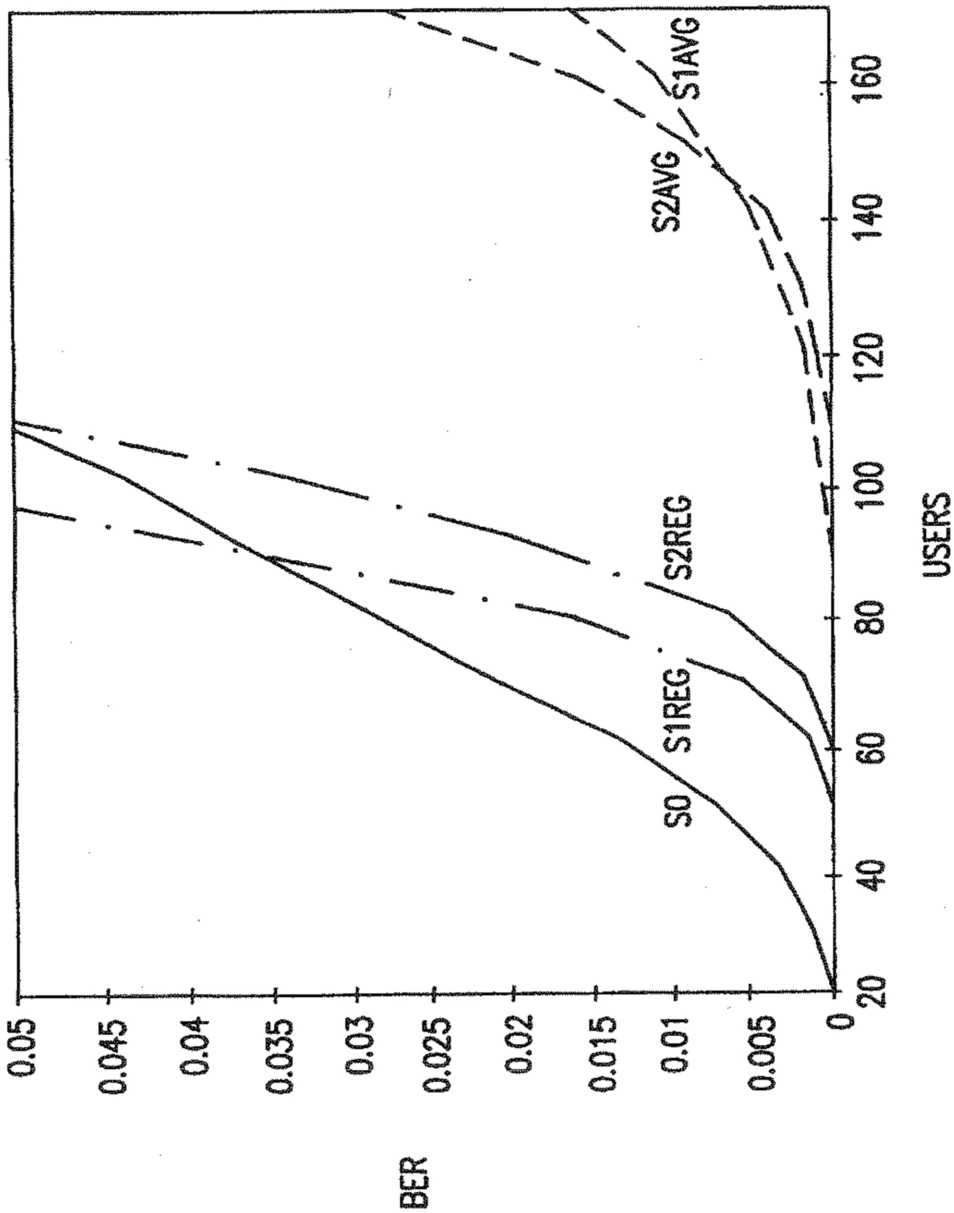

S0
S1
S2
S3
S4
USERS
20
40
60
80
100
120
140
160
BER
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.05

FIG. 15



BER
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
USERS
20
40
60
80
100
120
140
160
S0
S1REG
S2REG
S2AVG
S1AVG

FIG. 16

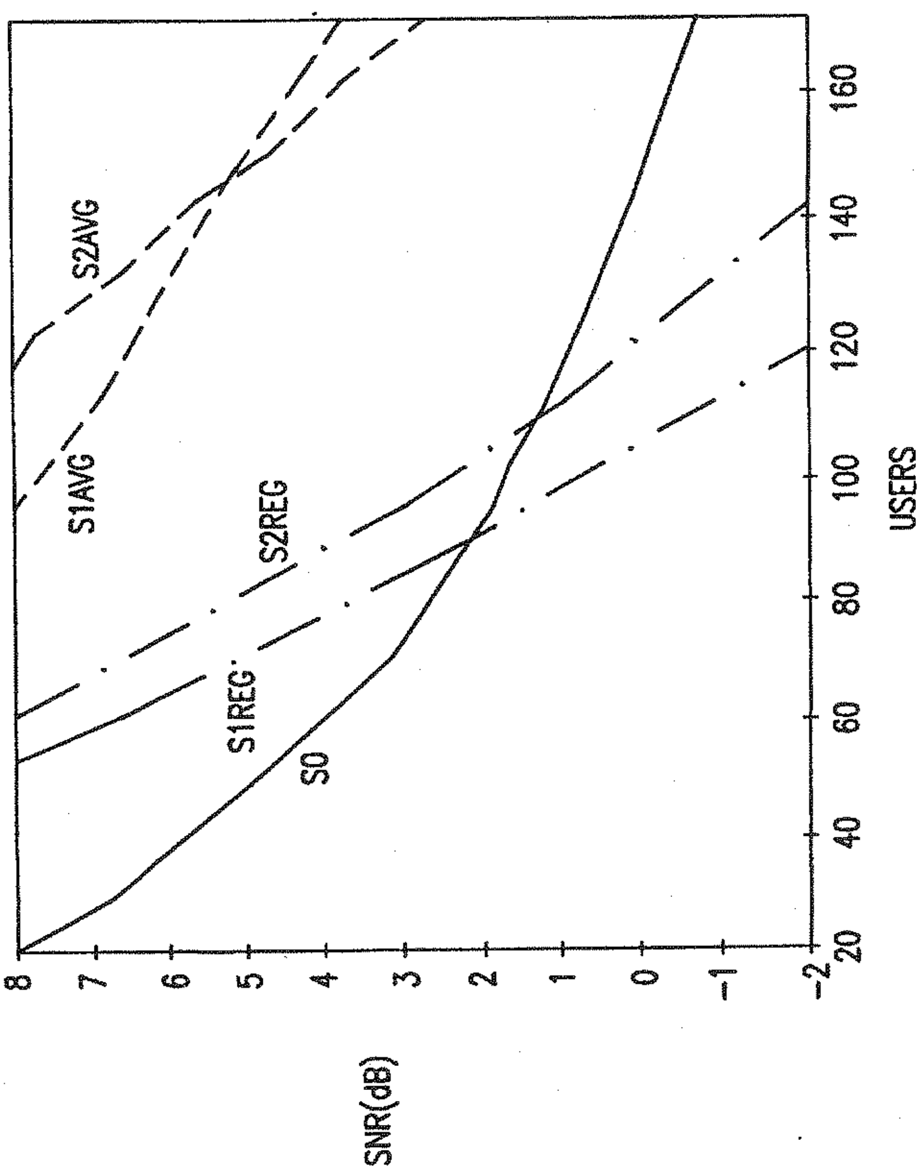

S2AVG
S1AVG
S2REG
S1REG
S0
SNR(dB)
USERS
8
7
6
5
4
3
2
1
0
−1
−2
20
40
60
80
100
120
140
160

FIG. 17

SPREAD SPECTRUM CDMA SUBTRACTIVE INTERFERENCE CANCELER SYSTEM

This patent stems from a continuation application of patent application entitled, SPREAD SPECTRUM CDMA INTERFERENCE CANCELER SYSTEM, having Ser. No. 08/279,477, and filing date Jul. 26, 1994, now U.S. Pat. No. 5,553,062, issued Sep. 3, 1996, which was a continuation-in-part of patent application entitled, SPREAD SPECTRUM CDMA INTERFERENCE CANCELER AND METHOD, having Ser. No. 08/051,017, and filing date Apr. 22, 1993, now U.S. Pat. No. 5,363,403, issued Nov. 8, 1994. The benefit of the earlier filing date of the parent patent applications is claimed pursuant to 35 U.S.C. § 120.

BACKGROUND OF THE INVENTION

This invention relates to spread-spectrum communications, and more particularly to an interference canceler and method for reducing interference in a direct sequence, code division multiple access receiver.

DESCRIPTION OF THE RELEVANT ART

Direct sequence, code division multiple access, spread-spectrum communications systems are capacity limited by interference caused by other simultaneous users. This is compounded if adaptive power control is not used, or is used but is not perfect.

Code division multiple access is interference limited. The more users transmitting simultaneously, the higher the bit error rate (BER). Increased capacity requires forward error correction (FEC) coding, which in turn, increases the data rate and limits capacity.

SUMMARY OF THE INVENTION

A general object of the invention is to reduce noise resulting from N−1 interfering signals in a direct sequence, spread-spectrum code division multiple access receiver.

The present invention, as embodied and broadly described herein, provides a spread-spectrum code division multiple access (CDMA) interference canceler for reducing interference in a spread-spectrum CDMA receiver having N channels. Each of the N channels is spread-spectrum processed by a distinct chip-code signal. The chip-code signal, preferably, is derived from a distinct pseudo-noise (PN) sequence, which may be generated from a distinct chip codeword. The interference canceler partially cancels N−1 interfering CDMA channels, and provides a signal-to-noise ratio (SNR) improvement of approximately N/PG, where PG is the processing gain. Processing gain is the ratio of the chip rate divided by the bit rate. By canceling or reducing interference, the SNR primarily may be due to thermal noise, and residual, interference-produced noise. Thus, the SNR may increase, lowering the BER, which reduces the demand for a FEC encoder/decoder.

The interference canceler, for a particular channel, includes a plurality of despreading means, a plurality of spread-spectrum-processing means, subtracting means, and channel-despreading means. Using a plurality of chip-code signals, the plurality of despreading means despreads the spread-spectrum CDMA signals as a plurality of despread signals, respectively. The plurality of spread-spectrum-processing means uses a timed version of the plurality of chip-code signals, for spread-spectrum processing the plurality of despread signals, respectively, with a chip-code signal corresponding to a respective despread signal. The timed version of a chip-code signal may be generated by delaying the chip-code signal from a chip-code-signal generator. Alternatively, a matched filter may detect a particular PN sequence in the spread-spectrum CDMA signal. A chip-code-signal generator may use the detected signal from the matched filter to trigger a timed version of the chip-code signal.

For recovering a particular CDMA channel using an i^{th} chip-code signal, the subtracting means subtracts from the spread-spectrum CDMA signal, each of the N−1 spread-spectrum-processed-despread signals, thereby generating a subtracted signal. The N−1 spread-spectrum-processed-despread signals do not include the spread-spectrum-processed-despread signal of the i^{th} channel corresponding to the i^{th} chip-code signal. The channel-despreading means despreads the subtracted signal with the i^{th} chip-code signal.

The present invention also includes a method for reducing interference in a spread-spectrum CDMA receiver having N channels. The method comprises the steps of despreading, using a plurality of chip-code signals, the spread-spectrum CDMA signal as a plurality of despread signals, respectively; spread-spectrum processing, using a timed version of the plurality of chip-code signals, the plurality of despread signals, respectively, with a chip-code signal corresponding to a respective despread signal; subtracting from the spread-spectrum CDMA signal, each of the N−1 spread-spectrum-processed-despread signals, with the N−1 spread-spectrum-processed-despread signals not including a spread-spectrum-processed despread signal of the i^{th} channels, thereby generating a subtracted signal; and, despreading the subtracted signal having the i^{th} chip-code signal.

Additional objects and advantages of the invention are set forth in part in the description which follows, and in part are obvious from the description, or may be learned by practice of the invention. The objects and advantages of the invention also may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate preferred embodiments of the invention, and together with the description serve to explain the principles of the invention.

FIG. 1 is a block diagram of the spread-spectrum CDMA interference canceler using correlators;

FIG. 2 is a block diagram of the spread-spectrum CDMA interference canceler for processing multiple channels using correlators;

FIG. 3 is a block diagram of the spread-spectrum CDMA interference canceler using matched filters;

FIG. 4 is a block diagram of the spread-spectrum CDMA interference canceler for processing multiple channels using matched filters;

FIG. 5 is a block diagram of the spread-spectrum CDMA interference canceler having multiple iterations for processing multiple channels;

FIG. 6 illustrates theoretical performance characteristic for E_b/η=6 dB;

FIG. 7 illustrates theoretical performance characteristic for E_b/η=10 dB;

FIG. 8 illustrates theoretical performance characteristic for E_b/η=15 dB;

FIG. 9 illustrates theoretical performance characteristic for E_b/η=20 dB;

FIG. 10 illustrates theoretical performance characteristic for E_b/η=25 dB;

FIG. 11 illustrates theoretical performance characteristic for E_b/η=30 dB;

FIG. 12 is a block diagram of interference cancelers connected together;

FIG. 13 is a block diagram combining the outputs of the interference cancelers of FIG. 12;

FIG. 14 illustrates simulation performance characteristics for asynchronous, PG=100, Equal Powers, EbN=30 dB;

FIG. 15 illustrates simulation performance characteristics for asynchronous, PG=100, Equal Powers, EbN=30 dB;

FIG. 16 illustrates simulation performance characteristics for asynchronous, PG=100, Equal Powers, EbN=30 dB; and

FIG. 17 illustrates simulation performance characteristics for asynchronous, PG=100, Equal Powers, EbN=30 dB.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference now is made in detail to the present preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings, wherein like reference numerals indicate like elements throughout the several views.

In the exemplary arrangement shown in FIG. 1, a spread-spectrum code division multiple access (CDMA) interference canceler is provided for reducing interference in a spread-spectrum CDMA receiver having N channels. The present invention also works on a spread-spectrum code division multiplexed (CDM) system. Accordingly, without loss of generality, the term spread-spectrum CDMA signal, as used herein, includes spread-spectrum CDMA signals and spread-spectrum CDM signals. In a personal communications service, the interference canceler may be used at a base station or in a remote unit such as a handset.

FIG. 1 illustrates the interference canceler for the first channel, defined by the first chip-code signal. The interference canceler includes a plurality of despreading means, a plurality of timing means, a plurality of spread-spectrum-processing means, subtracting means, and first channel-despreading means.

Using a plurality of chip-code signals, the plurality of despreading means despreads the received spread-spectrum CDMA signals as a plurality of despread signals, respectively. In FIG. 1 the plurality of despreading means is shown as first despreading means, second despreading means, through N^{th} despreading means. The first despreading means includes a first correlator, which is embodied, by way of example, as a first mixer **51**, first chip-code-signal generator **52**, and a first integrator **54**. The first integrator **54** alternatively may be a first lowpass filter or a first bandpass filter. The first mixer **51** is coupled between the input **41** and the first chip-code-signal generator **52** and the first integrator **54**.

The second despreading means includes a second correlator, which is embodied, by way of example, as second mixer **61**, second chip-code-signal generator **62** and second integrator **64**. The second integrator **64** alternatively may be a second lowpass filter or a second bandpass filter. The second mixer **61**, is coupled between the input **41**, the second chip-code-signal generator **62**, and the second integrator **64**.

The N^{th} despreading means is depicted as an N^{th} correlator shown, by way of example, as N^{th} mixer **71**, and N^{th} chip-code-signal generator **72**, and N^{th} integrator **74**. The N^{th} integrator **74** alternatively may be an N^{th} lowpass filter or an N^{th} bandpass filter. The N^{th} mixer **71** is coupled between the input **41**, the N^{th} chip-code-signal generator **72** and the N^{th} integrator **74**.

As is well known in the art, the first through N^{th} despreading means may be embodied as any device which can despread a channel in a spread-spectrum signal.

The plurality of timing means may be embodied as a plurality of delay devices **53**, **63**, **73**. A first delay device **53** has a delay time T, which is approximately the same as the integration time T_b of first integrator **54**, or time constant of the first lowpass filter or first bandpass filter. A second delay device **63** has a time delay T, which is approximately the same as the integration time T_b of second integrator **64**, or time constant of the second lowpass filter or second bandpass filter. Similarly, the N^{th} delay device **73** has a time delay T, which is approximately the same as the integration time T_b of N^{th} integrator **74**, or time constant of the N^{th} lowpass filter or N^{th} bandpass filter. Typically, the integration times of the first integrator **54**, second integrator **64** through N^{th} integrator **74** are the same. If lowpass filters are used, then typically the time constants of the first lowpass filter, second lowpass filter through N^{th} lowpass filter are the same. If bandpass filters are used, then the time constants of the first bandpass filter, second bandpass filter through N^{th} bandpass filter are the same.

The plurality of spread-spectrum-processing means regenerates each of the plurality of despread signals as a plurality of spread-spectrum signals. The plurality of spread-spectrum-processing means uses a timed version, i.e. delayed version, of the plurality of chip-code signals, for spread-spectrum processing the plurality of despread signals, respectively, with a chip-code signal corresponding to a respective despread signal. The plurality of spread-spectrum-processing means is shown, by way of example, as a first processing mixer **55**, a second processing mixer **65**, through an N^{th} processing mixer **75**. The first processing mixer **55** is coupled to the first integrator **54**, and through a first delay device **53** to the first chip-code-signal generator **52**. The second processing mixer **65** is coupled to the second integrator **64**, and through the second delay device **63** to the second chip-code-signal generator **62**. The N^{th} processing mixer **75** is coupled to the N^{th} integrator **74** through the delay device **73** to the N^{th} chip-code-signal generator **72**.

For reducing interference to a channel using an i^{th} chip-code signal of the spread-spectrum CDMA signal, the subtracting means subtracts, from the spread-spectrum CDMA signal, each of the N−1 spread-spectrum-processed-despread signals not corresponding to the i^{th} channel. The subtracting means thereby generates a subtracted signal. The subtracting means is shown as a first subtractor **150**. The first subtractor **150** is shown coupled to the output of the second processing mixer **65**, through the N^{th} processing mixer **75**. Additionally, the first subtractor **150** is coupled through a main delay device **48** to the input **41**.

The i^{th} channel-despreading means despreads the subtracted signal with the i^{th} chip-code signal as the i^{th} channel. The first channel-despreading means is shown as a first channel mixer **147**. The first channel mixer **147** is coupled to the first delay device **53**, and to the first subtractor **150**. The first channel integrator **146** is coupled to the first channel mixer **147**.

The first chip-code-signal generator **52**, the second chip-code-signal generator **62**, through the N^{th} chip-code-signal generator **72** generate a first chip-code signal a second chip-code signal, through a N^{th} chip-code signal, respectively. The term "chip-code signal" is used herein to mean

the spreading signal of a spread-spectrum signal, as is well known in the art. Typically the chip-code signal is generated from a pseudorandom (PN) sequence. The first chip-code signal, the second chip code signal, through the N^{th} chip-code signal might be generated from a first PN sequence, a second PN sequence, through a N^{th} PN sequence, respectively. The first PN sequence is defined by or generated from a first chip codeword, the second PN sequence is defined by or generated from a second chip codeword, through the N^{th} PN sequence is defined by or generated from a N^{th} chip-codeword. Each of the first chip codeword, second chip codeword through N^{th} chip codeword is distinct, i.e. different from one another. In general, a chip codeword can be the actual sequence of a PN sequence, or used to define settings for generating the PN sequence. The settings might be the delay taps of shift registers, for example.

A first channel of a received spread-spectrum CDMA signal at input 41 is despread by first mixer 51 as a first despread signal, using the first chip-code signal generated by first chip-code-signal generator 52. The first despread signal from the first mixer 51 is filtered through first integrator 54. First integrator 54 integrates for a time T_b, the time duration of a symbol such as a bit. At the same time, the first chip-code signal is delayed by time T by delay device 53. The delay time T is approximately equal to the integration time T_b plus system or component delays. Systems or component delays are usually small, compared to integration time T_b.

The delayed version of the first chip-code signal is processed with the first despread signal from the output of the first integrator 54 using the first spreading mixer 55. The output of the first spreading mixer 55 is fed to subtractors other than first subtractor 150 for processing the second through N^{th} channels of the spread-spectrum CDMA signal.

For reducing interference to the first channel of the spread-spectrum CDMA signal, the received spread-spectrum CDMA signal is processed by the second through N^{th} despreaders as follows. The second channel of the spread-spectrum CDMA signal is despread by the second despreading means. At the second mixer 61, a second chip-code signal, generated by the second chip-code-signal generator 62, despreads the second channel of the spread-spectrum CDMA signal. The despread second channel is filtered through second integrator 64. The output of the second integrator 64 is the second despread signal. The second despread signal is spread-spectrum processed by second processing mixer 65 by a delayed version of the second chip-code signal. The second chip-code signal is delayed through delay device 63. The delay device 63 delays the second chip-code signal by time T. The second channel mixer 65 spread-spectrum processes a timed version, i.e. delayed version, of the second chip-code signal with the filtered version of the second spread-spectrum channel from second integrator 64. The term "spread-spectrum process" as used herein includes any method for generating a spread-spectrum signal by mixing or modulating a signal with a chip-code signal. Spread-spectrum processing may be done by product devices, EXCLUSIVE-OR gates, matched filters, or any other device or circuit as is well known in the art.

Similarly, the N^{th} channel of the spread-spectrum CDMA signal is despread by the N^{th} despreading means. Accordingly, the received spread-spectrum CDMA signal has the N^{th} channel despread by N^{th} mixer 71, by mixing the spread-spectrum CDMA signal with the N^{th} chip-code signal from N^{th} chip-code-signal generator 72. The output of the N^{th} mixer 71 is filtered by N^{th} integrator 74. The output of the N^{th} integrator 74, which is the N^{th} despread signal, is a

despread and filtered version of the N^{th} channel of the spread-spectrum CDMA signal. The N^{th} despread signal is spread-spectrum processed by a delayed version of the N^{th} chip-code signal. The N^{th} chip-code signal is delayed through N^{th} delay device 73. The N^{th} processing mixer 75 spread-spectrum processes the timed version, i.e. a delayed version, of the N^{th} chip-code signal with the N^{th} despread signal.

At the first subtractor 150, each of the outputs of the second processing mixer 65 through the N^{th} processing mixer 75 is subtracted from a timed version, i.e. a delayed version, of the spread-spectrum CDMA signal from input 41. The delay of the spread-spectrum CDMA signal is timed through the first main delay device 48. Typically, the delay of the first main delay device 48 is time T, which is approximately equal to the integration time of the first integrator 54 through N^{th} integrator 74.

At the output of the first subtractor 150, is generated a first subtracted signal. The first subtracted signal, for the first channel of the spread-spectrum CDMA signal, is defined herein to be the outputs from the second processing mixer 65 through N^{th} processing mixer 75, subtracted from the delayed version of the spread-spectrum CDMA signal. The second subtracted signal through N^{th} subtracted signal are similarly defined.

The delayed version of the first chip-code signal from the output of first delay device 53 is used to despread the output of the first subtractor 150. Accordingly, the first subtracted signal is despread by the first chip-code signal by first channel mixer 147. The output of the first channel mixer 147 is filtered by first channel integrator 147. This produces an output estimate d_1 of the first channel of the spread-spectrum CDMA signal.

As illustratively shown in FIG. 2, a plurality of subtractors 150, 250, 350, 450 can be coupled appropriately to the input 41 and to a first spreading mixer 55, second spreading mixer 65, third spreading mixer, through an N^{th} spreading mixer 75 of FIG. 1. The plurality of subtractors 150, 250, 350, 450 also are coupled to the main delay device 48 from the input 41. This arrangement can generate a first subtracted signal from the first subtractor 150, a second subtracted signal from the second subtractor 250, a third subtracted signal from the third subtractor 350, through an N^{th} subtracted signal from an N^{th} subtractor 450.

The outputs of the first subtractor 150, second subtractor 250, third subtractor 350, through the N^{th} subtractor 450 are each coupled to a respective first channel mixer 147, second channel mixer 247, third channel mixer 347, through N^{th} channel mixer 447. Each of the channel mixers is coupled to a delayed version of the first chip-code signal, g_1 (t-T), second chip-code signal, g_2 (t-T), third chip-code signal, g_3 (t-T), through N^{th} chip-code signal, g_N (t-T). The outputs of each of the respective first channel mixer 147, second channel mixer 247, third channel mixer 347, through N^{th} channel mixer 447 are coupled to a first channel integrator 146, second channel integrator 246, third channel integrator 346 through N^{th} channel integrator 446, respectively. At the output of each of the channel integrators is produced an estimate of the respective first channel d_1, second channel d_2, third channel d_3, through N^{th} channel d_N.

Referring to FIG. 1, use of the present invention is illustrated for the first channel of the spread-spectrum CDMA signal, with the understanding that the second through N^{th} CDMA channels work similarly. A received spread-spectrum CDMA signal at input 41 is delayed by delay device 48 and fed to the first subtractor 150. The

spread-spectrum CDMA signal has the second channel through N^{th} channel despread by second mixer 61 using the second chip-code signal, through the N^{th} mixer 71 using the N^{th} chip-code signal. The respective second chip-code signal through the N^{th} chip-code signal are generated by the second chip-code-signal generator 62 through the N^{th} chip-code-signal generator 72. The second channel through N^{th} channel are despread and filtered through the second integrator 64 through the N^{th} integrator 74, respectively. The despreading removes, partially or totally, the non-despread channels at the outputs of each of the second integrator 64 through N^{th} integrator 74.

In a preferred embodiment, each of the chip-code signal used for the first chip-code-signal generator 52, second chip-code-signal generator 62 through the N^{th} chip-code-signal generator 72, are orthogonal to each other. Use of chip-code signals having orthogonality however, is not required for operation of the present invention. When using orthogonal chip-code signals, the despread signals have the respective channel plus noise at the output of each of the integrators. With orthogonal chip-code signals, theoretically the mixers remove channels orthogonal to the despread channel. The respective channel is spread-spectrum processed by the respective processing mixer.

At the output of the second processing mixer 65 through the N^{th} processing mixer 75 is a respread version of the second channel through the N^{th} channel, plus noise components contained therein. Each of the second channel through N^{th} channel is then subtracted from the received spread-spectrum CDMA signal by the first subtractor 150. The first subtractor 150 produces the first subtracted signal. The first subtracted signal is despread by a delayed version of the first chip-code signal by first channel mixer 147, and filtered by first channel filter 146. Accordingly, prior to despreading the first channel of the spread-spectrum CDMA signal, the second through N^{th} channels plus noise components aligned with these channels are subtracted from the received spread-spectrum CDMA signal. As illustratively shown in FIG. 3, an alternative embodiment of the spread-spectrum CDMA interference canceler includes a plurality of first despreading means, a plurality of spread-spectrum-processing means, subtracting means, and second despreading means. In FIG. 3, the plurality of despreading means is shown as first despreading means, second despreading means through N^{th} despreading means. The first despreading means is embodied as a first matched filter 154. The first matched filter 154 has an impulse response matched to the first chip-code signal, which is used to spread-spectrum process and define the first channel of the spread-spectrum CDMA signal. The first matched filter 154 is coupled to the input 41.

The second despreading means is shown as second matched filter 164. The second matched filter 164 has an impulse response matched to the second chip-code signal, which is used to spread-spectrum process and define the second channel of the spread-spectrum CDMA signal. The second matched filter 164 is coupled to the input 41.

The N^{th} despreading means is shown an N^{th} matched filter 174. The N^{th} matched filter has an impulse response matched to the N^{th} chip-code signal, which is used to spread-spectrum process and define the N^{th} channel of the spread-spectrum CDMA signal. The N^{th} matched filter is coupled to the input 41.

The term matched filter, as used herein, includes any type of matched filter that can be matched to a chip-code signal. The matched filter may be a digital matched filter or analog matched filter. A surface acoustic wave (SAW) device may be used at a radio frequency (RF) or intermediate frequency (IF). Digital signal processors and application specific integrated circuits (ASIC) having matched filters may be used at RF, IF or baseband frequency.

In FIG. 3, the plurality of spread-spectrum-processing means is shown as the first processing mixer 55, the second processing mixer 65, through the N^{th} processing mixer 75. The first processing mixer 55 may be coupled through a first adjustment device 97 to the first chip-code-signal generator 52. The second processing mixer 65 may be coupled through the second adjustment device 98 to the second chip-code-signal generator 62. The N^{th} processing mixer 75 may be coupled through the N^{th} adjustment device 73 to the N^{th} chip-code-signal generator 72. The first adjustment device 97, second adjustment device 98 through N^{th} adjustment device 99 are optional, and are used as an adjustment for aligning the first chip-code signal, second chip-code signal through N^{th} chip-code signal with the first despread signal, second despread signal through N^{th} despread signal, outputted from the first matched filter 154, second matched filter 164 through N^{th} matched filter 174, respectively.

The subtracting means is shown as the first subtractor 150. The first subtractor 150 is coupled to the output of the second processing mixer 65, through the N^{th} processing mixer 75. Additionally, the first subtractor 150 is coupled through the main delay device 48 to the input 41.

The first channel-despreading means is shown as a first channel-matched filter 126. The first channel-matched filter 126 is coupled to the first subtractor 150. The first channel-matched filter 126 has an impulse response matched to the first chip-code signal.

A first channel of a received spread-spectrum CDMA signal, at input 41, is despread by first matched filter 154. The first matched filter 154 has an impulse response matched to the first chip-code signal. The first chip-code signal defines the first channel of the spread-spectrum CDMA signal, and is used by the first chip-code-signal generator 52. The first chip-code signal may be delayed by adjustment time τ by adjustment device 97. The output of the first matched filter 154 is spread-spectrum processed by the first processing mixer 55 with the first chip-code signal. The output of the first processing mixer 55 is fed to subtractors other than the first subtractor 150 for processing the second channel through N^{th} channel of the spread-spectrum CDMA signals.

For reducing interference to the first spread-spectrum channel, the received spread-spectrum CDMA signal is processed by the second despreading means through N^{th} despreading means as follows. The second matched filter 164 has an impulse response matched to the second chip-code signal. The second chip-code signal defines the second channel of the spread-spectrum CDMA signal, and is used by the second chip-code-signal generator 62. The second matched filter 164 despreads the second channel of the spread-spectrum CDMA signal. The output of the second matched filter 164 is the second despread signal. The second despread signal triggers second chip-code-signal generator 62. The second despread signal also is spread-spectrum processed by second processing mixer 65 by a timed version of the second chip-code signal. The timing of the second chip-code signal triggers the second despread signal from the second matched filter 164.

Similarly, the N^{th} channel of the spread-spectrum CDMA signal is despread by the N^{th} despreading means. Accordingly, the received spread-spectrum CDMA signal has the N^{th} channel despread by N^{th} matched filter 174. The

output of the N^{th} matched filter 174 is the N^{th} despread signal, i.e. a despread and filtered version of the N^{th} channel of the spread-spectrum CDMA signal. The N^{th} despread signal is spread-spectrum processed by a timed version of the N^{th} chip-code signal. The timing of the N^{th} chip-code signal is triggered by the N^{th} despread signal from the N^{th} matched filter 174. The N^{th} processing mixer 75 spread-spectrum processes the timed version of the N^{th} chip-code signal with the N^{th} despread signal.

At the first subtractor 150, each of the outputs of the second processing mixer 65 through the N^{th} processing mixer 75 are subtracted from a delayed version of the spread-spectrum CDMA signal from input 41. The delay of the spread-spectrum CDMA signal is timed through delay device 48. The time of delay device 48 is set to align the second through N^{th} spread-spectrum-processed-despread signals for subtraction from the spread-spectrum CDMA signal. This generates at the output of the first subtractor 150, a first subtracted signal. The subtracted signal is despread by the first channel-matched filter 126. This produces an output estimate d_1 of the first channel of the spread-spectrum CDMA signal.

As illustrated in FIG. 4, a plurality of subtractors 150, 250, 350, 450 can be coupled appropriately to the output from a first processing mixer, second processing mixer, third processing mixer, through a N^{th} processing mixer, and to a main delay device from the input. A first subtracted signal is outputted from the first subtractor 150, a second subtracted signal is outputted from the second subtractor 250, a third subtracted signal is outputted from the third subtractor 350, through an N^{th} subtractor signal is outputted from an N^{th} subtractor 450.

The output of the first subtractor 150, second subtractor 250, third subtractor 350, through the N^{th} subtractor 450 are each coupled to a respective first channel-matched filter 126, second channel-matched filter 226, third channel-matched filter 326, through N^{th} channel-matched filter 426. The first channel-matched filter 126, second channel-matched filter 226, third channel-matched filter 326 through N^{th} channel-matched filter 426 have an impulse response matched the first chip-code signal, second chip-code signal, third chip-code signal, through N^{th} chip-code signal, defining the first channel, second channel, third channel through N^{th} channel, respectively, of the spread-spectrum CDMA signal. At each of the outputs of the respective first channel-matched filter 126, second channel-matched filter 226, third channel-matched filter 326, through N^{th} channel-matched filter 426, is produced an estimate of the respective first channel d_1, second channel d_2, third channel d_3, through N^{th} channel d_n.

In use, the present invention is illustrated for the first channel of the spread-spectrum CDMA signal, with the understanding that the second channel through N^{th} channel work similarly. A received spread-spectrum CDMA signal at input 41 is delayed by delay device 48 and fed to subtractor 150. The same spread-spectrum CDMA signal has the second through N^{th} channel despread by the second matched filter 164 through the N^{th} matched filter 174. This despreading removes the other CDMA channels from the respective despread channel. In a preferred embodiment, each of the chip-code signals used for the first channel, second channel, through the N^{th} channel, is orthogonal to the other chip-code signals. At the output of the first matched filter 154, second matched filter 164 through N^{th} matched filter 174, are the first despread signal, second despread signal through N^{th} despread signal, plus noise.

The respective channel is spread-spectrum processed by the processing mixers. Accordingly, at the output of the second processing mixer 65 through the N^{th} processing mixer 75 is a spread version of the second despread signal through the N^{th} despread signal, plus noise components contained therein. Each of the spread-spectrum-processed-despread signals, is then subtracted from the received spread-spectrum CDMA signal by the first subtractor 150. This produces the first subtracted signal.

The first subtracted signal is despread by first channel-matched filter 126. Accordingly, prior to despreading the first channel of the spread-spectrum CDMA signal, the second channel through N^{th} channel plus noise components aligned with these channels, are subtracted from the received spread-spectrum CDMA signal.

As is well known in the art, correlators and matched filters may be interchanged to accomplish the same function. FIGS. 1 and 3 show alternate embodiments using correlators or matched filters. The arrangements may be varied. For example, the plurality of despreading means may be embodied as a plurality of matched filters, while the channel despreading means may be embodied as a correlator. Alternatively, the plurality of despreading means may be a combination of matched filters and correlators. Also, the spread-spectrum-processing means my be embodied as a matched filter or SAW, or as EXCLUSIVE-OR gates or other devices for mixing a despread signal with a chip-code signal. As is well known in the art, any spread-spectrum despreader or demodulator may despread the spread-spectrum CDMA signal. The particular circuits shown in FIGS. 1–4 illustrate the invention by way of example.

The concepts taught in FIGS. 1–4 may be repeated, as shown in FIG. 5. FIG. 5 illustrates a first plurality of interference cancelers 511, 512, 513, a second plurality of interference cancelers 521, 522, 523, through an N^{th} plurality of interference cancelers 531, 532, 533. Each plurality of interference cancelers includes appropriate elements as already disclosed, and referring to FIGS. 1–4. The input is delayed through a delay device in each interference canceler.

The received spread-spectrum CDMA signal has interference canceled initially by the first plurality of interference cancelers 511, 512, 513, thereby producing a first set of estimates, i.e. a first estimate d_{11}, a second estimate d_{12}, through an N^{th} estimate d_{1N}, of the first channel, second channel through the N^{th} channel, of the spread-spectrum CDMA signal. The first set of estimates can have interference canceled by the second plurality of interference cancelers 521, 522, 523. The first set of estimates $d_{11}, d_{12}, \ldots d_{1N}$, of the first channel, second channel through N^{th} channel, are input to the second plurality of interference cancelers, interference canceler 521, interference canceler 522 through N^{th} interference canceler 523 of the second plurality of interference cancelers. The second plurality of interference cancelers thereby produce a second set of estimates, i.e. $d_{21}, d_{22}, \ldots d_{2N}$, of the first channel, second channel, through N^{th} channel. Similarly, the second set estimates can pass through a third plurality of interference cancelers, and ultimately through an M^{th} set of interference cancelers 531, 532, 533, respectively.

The present invention also includes a method for reducing interference in a spread-spectrum CDMA receiver having N chip-code channels. Each of the N channels is identified by a distinct chip-code signal. The method comprises the steps of despreading, using a plurality of chip-code signals, the spread-spectrum CDMA signal as a plurality of despread signals, respectively. Using a timed version of the plurality of chip-code signals, the plurality of despread signals are spread-spectrum processed with a chip-code signal corre-

sponding to a respective despread signal. Each of the N−1 spread-spectrum-processed-despread signals, is subtracted from the spread-spectrum CDMA signal, with the N−1 spread-spectrum-processed-despread signals not including a spread-spectrum-processed signal of the i^{th} despread signal, thereby generating a subtracted signal. The subtracted signal is despread to generate the i^{th} channel.

The probability of error P_e for direct sequence, spread-spectrum CDMA system is:

$$P_e = \frac{1}{2} \mathrm{erfc}(\alpha\ \mathrm{SNR})^{1/2}$$

where erfc is complementary error function, SNR is signal-to-noise ratio, and $1 \leq \alpha \leq 2$. The value of α depends on how a particular interference canceler system is designed.

The SNR after interference cancellation and method is given by:

$$SNR = \frac{(PG/N)^{R+1}}{1 + (PG/N)^{R+1} \frac{1}{E_b/\eta} \frac{1-(N/PG)^{R+1}}{1-N/PG}}$$

where N is the number of channels, PG is the processing gain, R is the number of repetitions of the interference canceler, E_b is energy per information bit and η is noise power spectral density.

FIG. 6 illustrates theoretical performance characteristic, of the interference canceler and method for when $E_b/\eta=6$ dB. The performance characteristic is illustrated for SNR out of the interference canceler, versus PG/N. The lowest curve, for R=0, is the performance without the interference canceler. The curves, for R=1 and R=2, illustrates improved performance for using one and two iterations of the interference canceler as shown in FIG. 5. As PG/N−1, there is insufficient SNR to operate. If PG>N, then the output SNR from the interference canceler approaches E_b/η. Further, if $(N/PG)^{R+1} << 1$, then

$$SNR \rightarrow (E_b/\eta)(1-N/PG).$$

FIG. 7 illustrates the performance characteristic for when $E_b/\eta=10$ dB. FIG. 7 illustrates that three iterations of the interference canceler can yield a 4 dB improvement with PG/N=2.

FIG. 8 illustrates the performance characteristic for when E_b/η 15 dB. With this bit energy to noise ratio, two iterations of the interference canceler can yield 6 dB improvement for PG/N=2.

FIG. 9 illustrates the performance characteristic for when E_b/η 20 dB. With this bit energy to noise ratio, two iterations of the interference canceler can yield 6 dB improvement for PG/N=2. Similarly, FIGS. 10 and 11 shows that one iteration of the interference canceler can yield more than 10 db improvement for PG/N=2.

The present invention may be extended to a plurality of interference cancelers. As shown in FIG. 12, a received spread-spectrum signal, R(t), is despread and detected by CDMA/DS detector 611. Each of the channels is represented as outputs O_{01}, O_{02}, O_{03}, . . . , O_{0m}. Thus, each output is a despread, spread-spectrum channel from a received spread-spectrum signal, R(t).

Each of the outputs of the CDMA/DS detector 611 is passed through a plurality of interference cancelers 612, 613, . . .) 614, which are serially connected. Each of the spread-spectrum channels passes through the interference canceling processes as discussed previously. The input to each interference canceler is attained by sampling and holding the output of the previous stage once per bit time.

For channel i, the first interference canceler samples the output of the CDMA/DS detector at time $t=T+\tau_i$. This value is held constant as the input until $t=2T+\tau_i$ at which point the next bit value is sample. Thus, the input waveforms to the interference canceler are estimates, $\hat{d}_i(C-\tau_i)$, of the original data waveform, $d_i(t-\tau_i)$, and the outputs are second estimates, $\hat{\hat{d}}_i(t-\tau_i)$. The M spread-spectrum channel outputs O_{0i}, i=1, 2, . . . , M, are passed through interference canceler 612 to produce a new corresponding set of channel outputs O_{1i}, i=1, 2, . . . , M.

As shown in FIG. 13, the outputs of a particular spread-spectrum channel, which are at the output of each of the interference cancelers, may be combined. Accordingly, combiner 615 can combine the output of the first channel which is from CDMA/DS detector 611, and the output O_{11} from the first interference canceler 612, and the output O_{21} from the second interference canceler 613, through the output O_{N1} from the N^{th} interference canceler 614. Each output to be combined is of the corresponding bit. Therefore "s" bit time delays is inserted for each O_{s1}. The combined outputs are then passed through the decision device 616. This can be done for each spread spectrum channel, and therefore designate the outputs of each of the combiners 615, 617, 619 as averaged outputs O_1 for channel one, averaged output O_2 for channel two, and averaged output O_M for channel M. Each of the averaged outputs are sequentially passed through decision device 616, decision device 618, and decision device 620. Preferably, the averaged outputs have multiplying factor c_j which may vary according to a particular design. In a preferred embodiment, $c_j=\frac{1}{2}^j$. This allows the outputs of the various interference cancelers to be combined in a particular manner.

FIGS. 14–17 illustrate simulation performance characteristics for the arrangement of FIGS. 12 and 13. FIGS. 14–17 are for asynchronous channel (relative time delays are uniformly distributed between 0 and bit time, T), processing gain of 100, all user have equal powers, and thermal signal to noise ratio (E_bN of 30 dB). Length 8191 Gold codes are used for the PN sequences.

In FIG. 14, performance characteristic of each of the output stages of FIG. 12 is shown. Thus, S0 represents the BER performance at the output of CDMA/DS detector 611, S1 represents the BER performance at the output of interference canceler 612, S2 represents he BER performance a the output of interference canceler 613, etc. No combining of the outputs of the interference cancelers are used in determining the performance characteristic shown in FIG. 14. Instead, the performance characteristic is for repetitively using interference cancelers. As a guideline, in each of the subsequent figures the output for each characteristic of CDMA/DS detector 611 is shown in each figure.

FIG. 15 shows the performance characteristic when the output of subsequent interference cancelers are combined. This is shown for a particular channel. Thus, curve S0 is the output of the CDMA/DS detector 611. Curve S1 represents the BER performance of the average of the outputs of CDMA/DS detector 611 and interference canceler 612. Here $C_0=C_1=\frac{1}{2}$ $C_j=0$, j not equal to zero, one. Curve S2 represents the BER performance of the average output of interference canceler 613 and interference canceler 612. Curve S2 is determined using the combiner shown in FIG. 13. Here, C_1 and C_2 are set equal to ½ and all other C_j set to zero. Similarly, curve S3 is the performance of the output of a second and third interference canceler averaged together. Thus, curve S3 is the performance characteristic of the average between output of a second and third interference canceler. Curve S4 is the performance characteristic of the average output of a third and fourth interference canceler.

Only two interference cancelers are taken at a time for determining a performance characteristic of an average output of those to particular interference cancelers.

FIG. 16 shows the regular outputs for the CDMA/DS detector 611, and a first and second interference canceler 612, 613. Additionally, the average output of the CDMA/DS detector 611 and the first interference canceler 612 is shown as S1 AVG. The BER performance of the average of the outputs of the first interference canceler 612 and the second interference canceler 613 is shown as the average output S2 AVG.

FIG. 17 shows performance characteristic correspondence for those of FIG. 16, but interms of signal to-noise ratio in decibels(dB).

It will be apparent to those skilled in the art that various modifications can be made to the spread-spectrum CDMA interference canceler and method of the instant invention without departing from the scope or spirit of the invention, and it is intended that the present invention cover modifications and variations of the spread-spectrum CDMA interference canceler and method provided they come within the scope of the appended claims and their equivalents.

We claim:

1. A method for reducing interference in a spread-spectrum code division multiple access (CDMA) receiver having N channels, with each of the N channels identified by a distinct chip-code signal, using a first plurality of interference cancelers, comprising the steps of:

a. despreading, simultaneously, a plurality of spread-spectrum channels of a spread-spectrum CDMA signal as a plurality of despread signals, respectively;

b. spread-spectrum processing, simultaneously, using a timed version of a plurality of chip-code-signals, the plurality of despread signals, respectively, with a timed chip-code signal corresponding to a respective despread signal;

c. subtracting from the spread-spectrum CDMA signal, each of a plurality of N−1 spread-spectrum-processed-despread signals, with the plurality of N−1 spread-spectrum-processed-despread signals not including a spread-spectrum processed despread signal of an i^{th} despread signal, thereby generating a subtracted signal;

d. despreading the subtracted signal with an i^{th} timed chip-code signal as an i^{th} channel signal, producing a first set of estimates of the N channels;

e. inputting the first set of estimates to a second plurality of interference cancelers;

f. repeating steps a through d. using the second plurality of interference cancelers, producing a second set of estimates of the N channels;

g. inputting the second set of estimates to an M^{th} plurality of interference cancelers;

h. repeating steps a through d, using the M^{th} plurality of interference cancelers, producing an M^{th} set of estimates of the N channels; and

i. combining each estimate of the M^{th} set of estimates to produce an average.

2. A spread-spectrum code division multiple access (CDMA) interference-canceler system for reducing interference in a spread-spectrum CDMA receiver having N channels, with each of the N channels identified by a distinct chip-code signal, comprising:

a plurality of interference cancelers, each of said interference cancelers including,

a plurality of chip-code-signal generators for generating, simultaneously, a plurality of chip-code signals;

a plurality of correlators, responsive to a plurality of distinct chip-code-signals, for simultaneously despreading a plurality of spread-spectrum channels of a spread-spectrum CDMA signal as a plurality of despread signals, respectively;

a plurality of delay devices coupled to said plurality of chip-code-signal generators for delaying the plurality of chip-code signals as a timed plurality of chip-code signals, respectively;

a plurality of mixers, responsive to the timed plurality of chip-code signals, for spread-spectrum processing, simultaneously, the plurality of despread signals, respectively, with a timed chip-code-signal corresponding to a respective despread signal, producing N spread-spectrum-processed-despread signals;

a first subtractor, for subtracting from the spread-spectrum CDMA signal, all but a first one of the N spread-spectrum-processed-despread signals, thereby generating a first subtracted signal;

a second subtractor, for subtracting from the spread-spectrum CDMA signal, all but a second one of the N spread-spectrum-processed-despread signals, thereby generating a second subtracted signal; and

an n^{th} subtractor, for subtracting from the spread-spectrum CDMA signal, all but an n^{th} one of the N spread-spectrum-processed-despread signals, thereby generating an n^{th} subtracted signal;

a first channel correlator for despreading the first subtracted signal with a first timed chip-code signal as an estimate of a first channel;

a second channel correlator for despreading the second subtracted signal with a second timed chip-code signal as an estimate of a second channel;

an n^{th} channel correlator for despreading the n^{th} subtracted signal with an n^{th} timed chip-code signal as an estimate of an n^{th} channel signal;

a first combiner for combining a first plurality of estimates of the first channel from said plurality of interference cancelers;

a second combiner for combining a second plurality of estimates of the second channel from said plurality of interference cancelers; and

an n^{th} combiner for combining an n^{th} plurality of estimates of the n^{th} channel from said plurality of interference cancelers.

3. A spread-spectrum code division multiple access (CDMA) interference-canceler system for reducing interference in a spread-spectrum CDMA receiver having N channels, with each of the N channels identified by a distinct chip-code signal, comprising:

a plurality of interference cancelers, each of said interference cancelers including,

a plurality of matched filters, responsive to a plurality of distinct chip-code-signals, for simultaneously despreading a plurality of spread-spectrum channels of a spread-spectrum CDMA signal as a plurality of despread signals, respectively;

a plurality of chip-code-signal generators, responsive to the plurality of despread signals from the plurality of matched filters, for generating, simultaneously, a timed plurality of chip-code signals, respectively;

a plurality of mixers, responsive to the plurality of despread signals from the plurality of matched filters and the timed plurality of chip-code signals from the plurality of chip-code-signal generators, respectively, for spread-spectrum processing,

simultaneously, the plurality of despread signals with a respective timed chip-code signal, producing N spread-spectrum-processed-despread signals;

a first subtractor, for subtracting from the spread-spectrum CDMA signal, all but a first one of the N spread-spectrum-processed-despread signals, thereby generating a first subtracted signal;

a second subtractor, for subtracting from the spread-spectrum CDMA signal, all but a second one of the N spread-spectrum-processed-despread signals, thereby generating a second subtracted signal; and

an n^{th} subtractor, for subtracting from the spread-spectrum CDMA signal, all but an n^{th} one of the N spread-spectrum-processed-despread signals, thereby generating an n^{th} subtracted signal;

a first channel-matched filter for despreading the first subtracted signal with a first timed chip-code signal as an estimate of a first channel;

a second channel-matched filter for despreading the second subtracted signal with a second timed chip-code signal as an estimate of a second channel;

an n^{th} channel-matched filter for despreading the n^{th} subtracted signal with an n^{th} timed chip-code signal as an estimate of an n^{th} channel;

a first combiner for combining a first plurality of estimates of the first channel from said plurality of interference cancelers;

a second combiner for combining a second plurality of estimates of the second channel from said plurality of interference cancelers; and

an n^{th} combiner for combining an n^{th} plurality of estimates of the n^{th} channel from said plurality of interference cancelers.

4. A method for reducing interference in a spread-spectrum code division multiple access (CDMA) receiver having N channels, with each of the N channels identified by a distinct chip-code signal, using a first plurality of interference cancelers, comprising the steps of:

a. despreading, simultaneously, a plurality of spread-spectrum channels of a spread-spectrum CDMA signal as a plurality of despread signals, respectively;

b. spread-spectrum processing, simultaneously, the plurality of despread signals with a respective plurality of timed-chip-code signals, each of said plurality of timed-chip-code signals corresponding to a respective one of the plurality of despread signals, producing N spread-spectrum-processed-despread signals;

c. subtracting from the spread-spectrum CDMA signal, all but a first one of the N spread-spectrum-processed-despread signals, thereby generating a first subtracted signal;

d. subtracting from the spread-spectrum CDMA signal, all but a second one of the N spread-spectrum-processed-despread signals, thereby generating a second subtracted signal;

e. subtracting from the spread-spectrum CDMA signal, all but an n^{th} one of the N spread-spectrum-processed-despread signals, thereby generating an n^{th} subtracted signal;

f. despreading the first subtracted signal with a first timed-chip-code signal as an estimate of a first channel;

g. despreading the second subtracted signal with a second timed-chip-code signal as an estimate of a second channel;

h. despreading the n^{th} subtracted signal with an n^{th} timed-chip-code signal as an estimate of an n^{th} channel;

i. combining a first plurality of estimates of the first channel;

j. combining a second plurality of estimates of the second channel; and

k. combining an n^{th} plurality of estimates of the n^{th} channel.

5. The method as set forth in claim 4, further comprising the steps of:

l. processing the first plurality of estimates, the second plurality of estimates, and the n^{th} plurality of estimates as a plurality of processed estimates;

m. inputting the plurality of processed estimates to a second plurality of interference cancelers; and

n. repeating steps a through k, using the second plurality of interference cancelers.

6. A spread-spectrum code division multiple access (CDMA) interference-canceler system having a plurality of interference cancelers for reducing interference in a spread-spectrum CDMA receiver having N channels, with each of the N channels identified by a distinct chip-code signal, comprising:

a plurality of chip-code-signal generators for generating, simultaneously, a plurality of chip-code signals;

despreading means, responsive to a plurality of distinct chip-code-signals, for simultaneously despreading a plurality of spread-spectrum channels of a spread-spectrum CDMA signal as a plurality of despread signals, respectively;

a plurality of delay devices coupled to said plurality of chip-code-signal generators for delaying the plurality of chip-code signals as a plurality of timed-chip-code signals, respectively;

a first spreading mixer for spread-spectrum processing a first despread signal, of the plurality of despread signals, with a first timed-chip-code signal, of the plurality of timed-chip-code signals, to produce a first spread-spectrum-processed-despread signal;

a second spreading mixer for spread-spectrum processing a second despread signal, of the plurality of despread signals, with a second timed-chip-code signal, of the plurality of time-chip-code signals, to produce a second spread-spectrum-processed despread signal;

an n^{th} spreading mixer for spread-spectrum processing an n^{th} despread signal, of the plurality of despread signals, with an n^{th} timed-chip-code signal, of the plurality of timed-chip-code signals, to produce an n^{th} spread-spectrum-processed-despread signal;

a first subtractor, for subtracting from the spread-spectrum CDMA signal, all but the first spread-spectrum-processed-despread signal, thereby generating a first subtracted signal;

a second subtractor, for subtracting from the spread-spectrum CDMA signal, all but the second spread-spectrum-processed-despread signal, thereby generating a second subtracted signal; and

an n^{th} subtractor, for subtracting from the spread-spectrum CDMA signal, all but the n^{th} spread-spectrum-processed-despread signal, thereby generating an n^{th} subtracted signal;

a first channel correlator for despreading the first subtracted signal with a first timed-chip-code signal as an estimate of a first channel;

a second channel correlator for despreading the second subtracted signal with a second timed-chip-code signal as an estimate of a second channel;

an n^{th} channel correlator for despreading the n^{th} subtracted signal with an n^{th} timed-chip-code signal as an estimate of an n^{th} channel signal;

a first combiner for combining a first plurality of estimates of the first channel from said plurality of interference cancelers as a first plurality of averaged estimates;

a second combiner for combining a second plurality of estimates of the second channel from said plurality of interference cancelers as a second plurality of averaged estimates;

an n^{th} combiner for combining an n^{th} plurality of estimates of the n^{th} channel from said plurality of interference cancelers as an n^{th} plurality of averaged estimates; and

decision means for processing the first plurality of averaged estimates, the second plurality of averaged estimates, and the n^{th} plurality of averaged estimates.

7. The spread-spectrum CDMA interference-canceler system as set forth in claim 6, said plurality of delay devices comprising;

a first delay device for delaying a first chip-code signal by a first time delay to generate a first timed-chip-code signal;

a second delay device for delaying a second chip-code signal by a second time delay to generate a second timed-chip-code signal; and

an n^{th} delay device for delaying an n^{th} chip-code signal by an n^{th} time delay to generate an n^{th} timed-chip-code signal.

8. The spread-spectrum CDMA interference-canceler system as set forth in claim 6, said despreading means comprising:

a plurality of correlators.

9. The spread-spectrum CDMA interference-canceler system as set forth in claim 6, said despreading means comprising:

a plurality of matched filters.

10. The spread-spectrum CDMA interference-canceler system as set forth in claim 9, said plurality of delay devices comprising;

a first adjustment device for aligning a first chip-code signal with the first despread signal;

a second adjustment device for aligning a second chip-code signal with the second despread signal; and

an n^{th} adjustment device for aligning an n^{th} chip-code signal with the n^{th} despread signal.

11. A spread-spectrum code division multiple access (CDMA) interference-canceler system having a plurality of interference cancelers for reducing interference in a spread-spectrum CDMA receiver having N channels, with each of the N channels identified by a distinct chip-code signal, comprising:

a plurality of matched filters, responsive to a plurality of distinct chip-code-signals, for simultaneously despreading a plurality of spread-spectrum channels of a spread-spectrum CDMA signal as a plurality of despread signals, respectively;

a plurality of chip-code-signal generators, responsive to the plurality of despread signals from the plurality of matched filters, for generating, simultaneously, a plurality of timed-chip-code signals, respectively;

a first spreading mixer for spread-spectrum processing a first despread signal, of the plurality of despread signals, with a first timed-chip-code signal, of the plurality of timed-chip-code signals, to produce a first spread-spectrum-processed-despread signal;

a second spreading mixer for spread-spectrum processing a second despread signal, of the plurality of despread signals, with a second timed-chip-code signal, of the plurality of timed-chip-code signals, to produce a second spread-spectrum-processed-despread signal;

an n^{th} spreading mixer for spread-spectrum processing an n^{th} despread signal, of the plurality of despread signals, with an n^{th} timed-chip-code signal, of the plurality of timed-chip-code signals, to produce an n^{th} spread-spectrum-processed-despread signal;

a first subtractor, for subtracting from the spread-spectrum CDMA signal, all but the first spread-spectrum-processed-despread signal, thereby generating a first subtracted signal;

a second subtractor, for subtracting from the spread-spectrum CDMA signal, all but the second spread-spectrum-processed-despread signal, thereby generating a second subtracted signal; and

an n^{th} subtractor, for subtracting from the spread-spectrum CDMA signal, all but the n^{th} spread-spectrum-processed-despread signal, thereby generating an n^{th} subtracted signal;

a first channel-matched filter for despreading the first subtracted signal with the first timed-chip-code signal as an estimate of a first channel;

a second channel-matched filter for despreading the second subtracted signal with the second timed-chip-code signal as an estimate of a second channel;

an n^{th} channel-matched filter for despreading the n^{th} subtracted signal with the n^{th} timed-chip-code signal as an estimate of an n^{th} channel;

a first combiner for combining a first plurality of estimates of the first channel from said plurality of interference cancelers;

a second combiner for combining a second plurality of estimates of the second channel from said plurality of interference cancelers;

an n^{th} combiner for combining an n^{th} plurality of estimates of the n^{th} channel from said plurality of interference cancelers; and

decision means for processing the combined estimates.

12. The spread-spectrum CDMA interference-canceler system as set forth in claim 11, said decision means comprising:

a first decision device for processing the first combined plurality of estimates;

a second decision device for processing the second combined plurality of estimates; and

a third decision device for processing the third combined plurality of estimates.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,719,852 Page 1 of 2

DATED : February 17, 1998

INVENTOR(S) : Schilling et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On page 2, left column, line 45, delete "Poorand" and insert therefor --Poor and--.

On page 2, right column, line 6, after "Multiple" insert a dash.

On page 2, right column, line 18, please delete "Rupas" and insert therefor --R. Lupas--.

On page 2, at the bottom of the right column, insert --F. Xie, C.X. Rushforth, and R.J. Short, "Multiuser Signal Detection Using Sequential Decoding", IEEE Trans. Commun., Vol. 38, No. 5, pp. 578-583, May 1990.--

At column 4, line 65, after "signal", insert --,--.

At column 11, line 34, please delete "PG/N-1" and insert therefor --PG/N-⟩1--.

At column 11, line 62, please delete ")".

At column 12, line 5, please delete "(C-T_i)" and insert therefor --(t-T_i)--.

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,719,852 Page 2 of 2

DATED : February 17, 1998

INVENTOR(S) : Schilling et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

At column 12, line 43, please delete "he" and insert therefor --the--.

At column 12, line 43, after "performance" please delete "a" and insert therefor --at--.

Signed and Sealed this

Eighteenth Day of August, 1998

Bruce Lehman

Attest:

BRUCE LEHMAN

Attesting Officer

Commissioner of Patents and Trademarks

US006014373A

United States Patent [19]

Schilling et al.

[11] **Patent Number: 6,014,373**

[45] **Date of Patent: *Jan. 11, 2000**

[54] **SPREAD SPECTRUM CDMA SUBTRACTIVE INTERFERENCE CANCELER SYSTEM**

[75] Inventors: **Donald L. Schilling**, Sands Point; **John Kowalski**; **Shimon Moshavi**, both of New York, all of N.Y.

[73] Assignee: **InterDigital Technology Corporation**, Wilmington, Del.

[*] Notice: This patent is subject to a terminal disclaimer.

[21] Appl. No.: **08/939,146**

[22] Filed: **Sep. 29, 1997**

Related U.S. Application Data

[63] Continuation of application No. 08/654,994, May 29, 1996, Pat. No. 5,719,852, which is a continuation of application No. 08/279,477, Jul. 26, 1994, Pat. No. 5,553,062, which is a continuation-in-part of application No. 08/051,017, Apr. 22, 1993, Pat. No. 5,363,403.

[51] **Int. Cl.**[7] **H04B 1/707**

[52] **U.S. Cl.** **370/342**; 370/441; 370/479; 375/206; 375/207; 375/343; 375/346; 380/34

[58] **Field of Search** 370/201, 310, 370/342, 331–333, 335, 464, 479, 441; 375/200, 205, 206–210, 343, 346; 380/34

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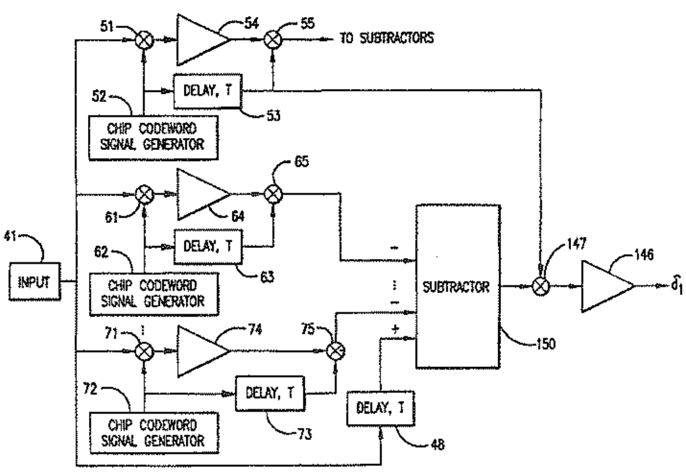
Primary Examiner—Douglas W. Olms
Assistant Examiner—Seema S Rao
Attorney, Agent, or Firm—Volpe and Koenig, P.C.

[57] **ABSTRACT**

A spread-spectrum code division multiple access interference canceler for reducing interference in a direct sequence CDMA receiver having N chip-code channels. The interference canceler includes a plurality of correlators or matched filters, a plurality of spread-spectrum-processing circuits, subtracting circuits, and channel correlators or channel-matched filters. Using a plurality of chip-code signals, the plurality of correlators despreads the spread-spectrum CDMA signal as a plurality of despread signals, respectively. The plurality of spread-spectrum-processing circuits uses a timed version of the plurality of chip-code signals, for spread-spectrum processing the plurality of despread signals, respectively, with a chip-code-signal corresponding to a respective despread signal. For recovering a code channel using an i^{th} chip-code-signal, the subtracting circuits subtracts from the spread-spectrum CDMA signal, each of the N−1 spread-spectrum-processed-despread signals thereby generating a subtracted signal. The N−1 spread-spectrum-processed-despread signals do not include the spread-spectrum-processed-despread signal of the i^{th} channel of the spread-spectrum CDMA signal. The channel correlator or channel-matched filter despreads the subtracted signal.

18 Claims, 14 Drawing Sheets



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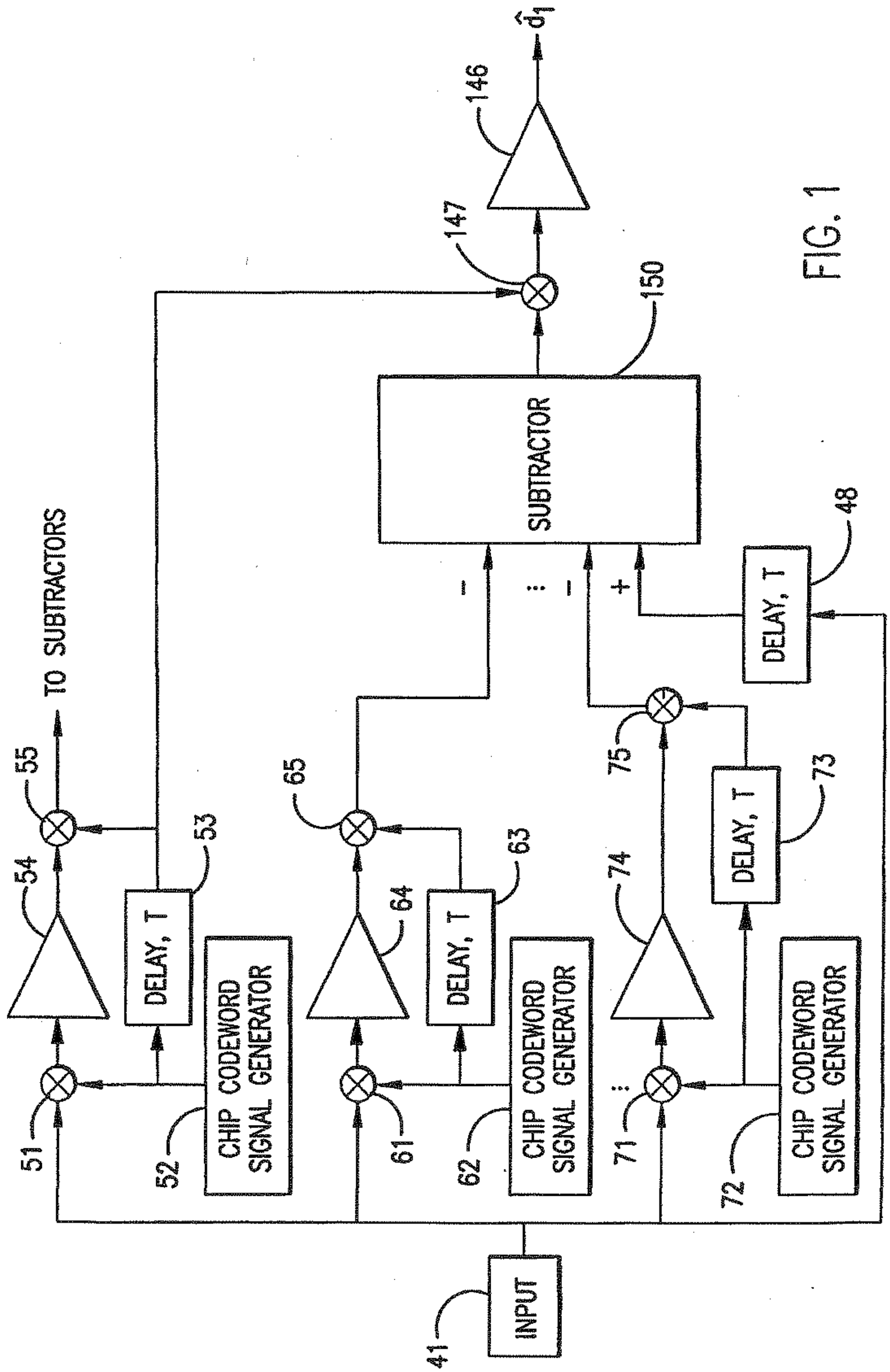
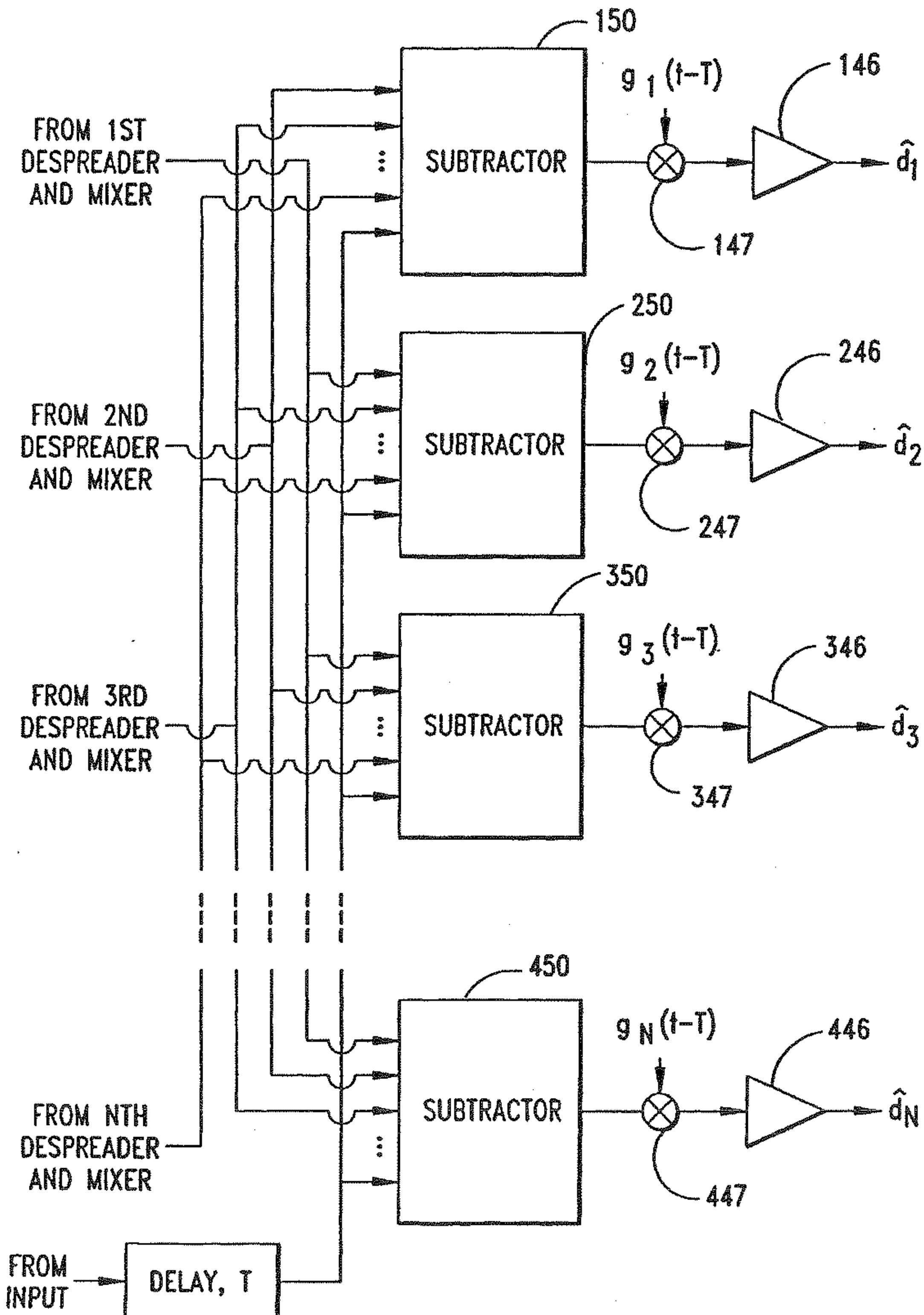

INPUT
41
CHIP CODEWORD SIGNAL GENERATOR
52
CHIP CODEWORD SIGNAL GENERATOR
62
CHIP CODEWORD SIGNAL GENERATOR
72
DELAY, T
53
DELAY, T
63
DELAY, T
73
DELAY, T
48
51
54
55
61
64
65
71
74
75
TO SUBTRACTORS
SUBTRACTOR
150
147
146
$\hat{d}_1$
−
−
+

FIG. 1



150
FROM 1ST DESPREADER AND MIXER
SUBTRACTOR
g 1 (t−T)
146
147
d̂1
250
FROM 2ND DESPREADER AND MIXER
SUBTRACTOR
g 2 (t−T)
246
247
d̂2
350
FROM 3RD DESPREADER AND MIXER
SUBTRACTOR
g 3 (t−T)
346
347
d̂3
450
FROM NTH DESPREADER AND MIXER
SUBTRACTOR
g N (t−T)
446
447
d̂N
FROM INPUT
DELAY, T

FIG. 2

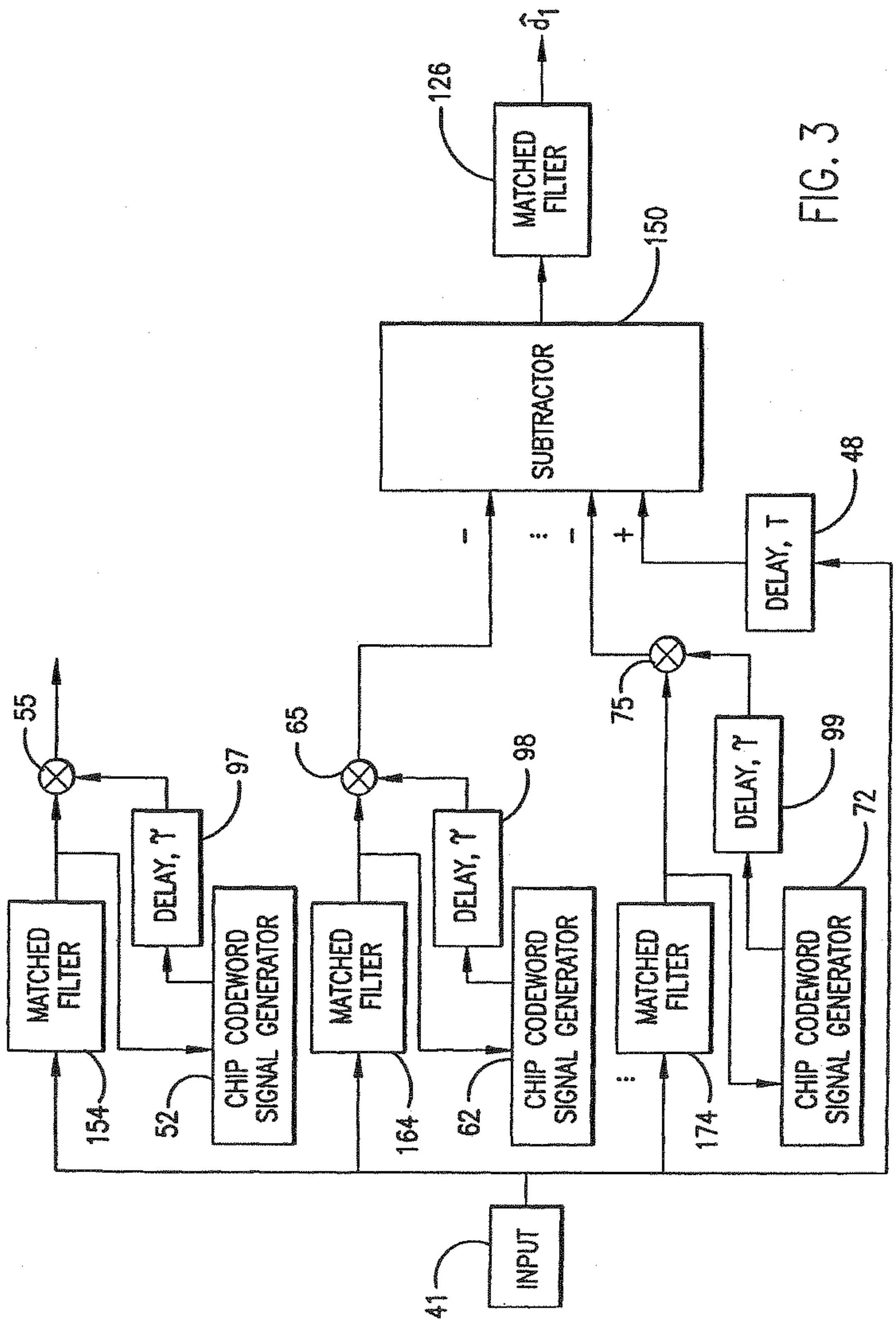
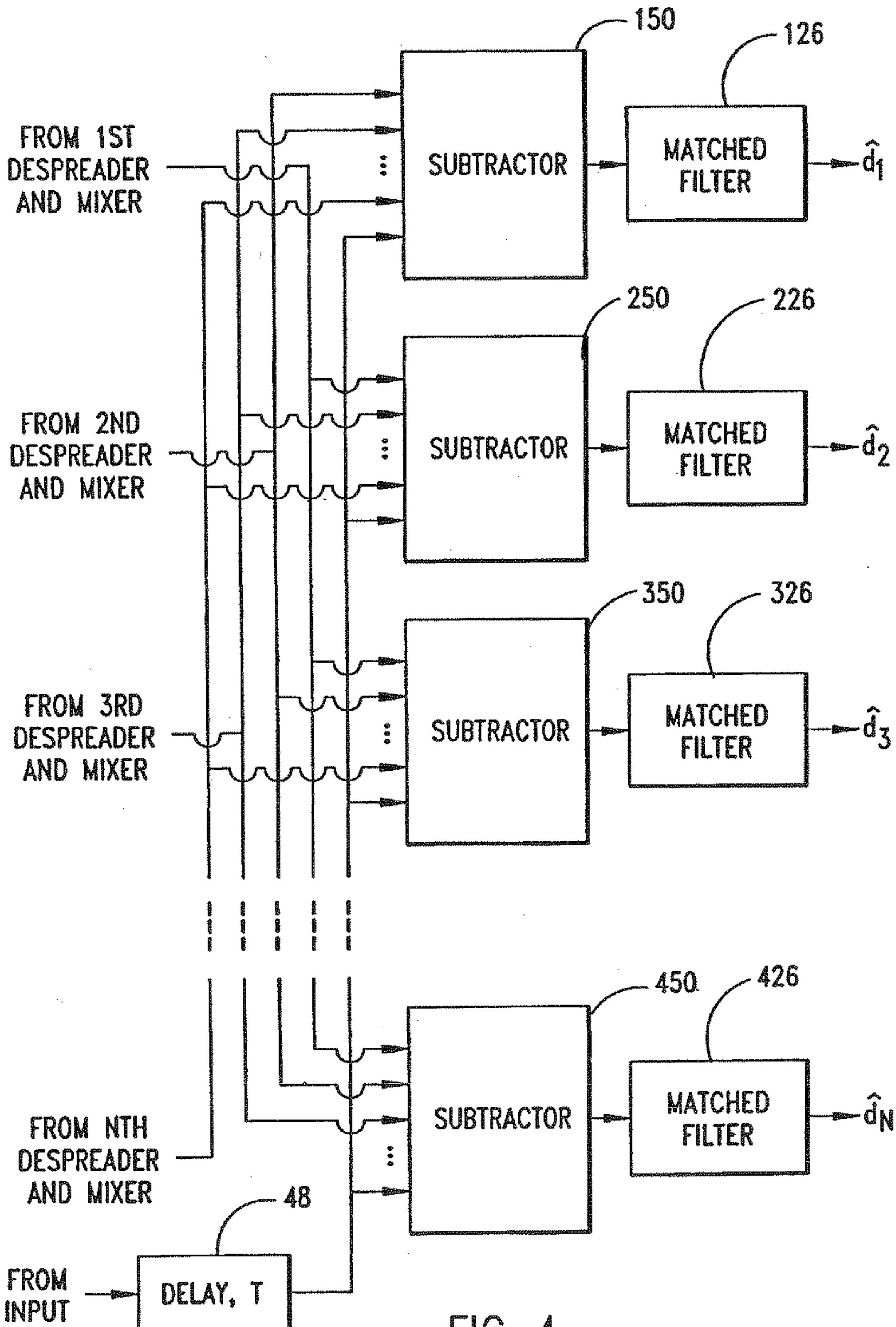

INPUT
41
MATCHED FILTER
154
164
174
CHIP CODEWORD SIGNAL GENERATOR
52
62
72
DELAY, τ
97
98
99
55
65
75
DELAY, T
48
SUBTRACTOR
150
MATCHED FILTER
126
$\hat{d}_1$

FIG. 3



150
126
FROM 1ST DESPREADER AND MIXER
SUBTRACTOR
MATCHED FILTER
$\hat{d}_1$
250
226
FROM 2ND DESPREADER AND MIXER
SUBTRACTOR
MATCHED FILTER
$\hat{d}_2$
350
326
FROM 3RD DESPREADER AND MIXER
SUBTRACTOR
MATCHED FILTER
$\hat{d}_3$
450
426
FROM NTH DESPREADER AND MIXER
SUBTRACTOR
MATCHED FILTER
$\hat{d}_N$
48
FROM INPUT
DELAY, T

FIG. 4

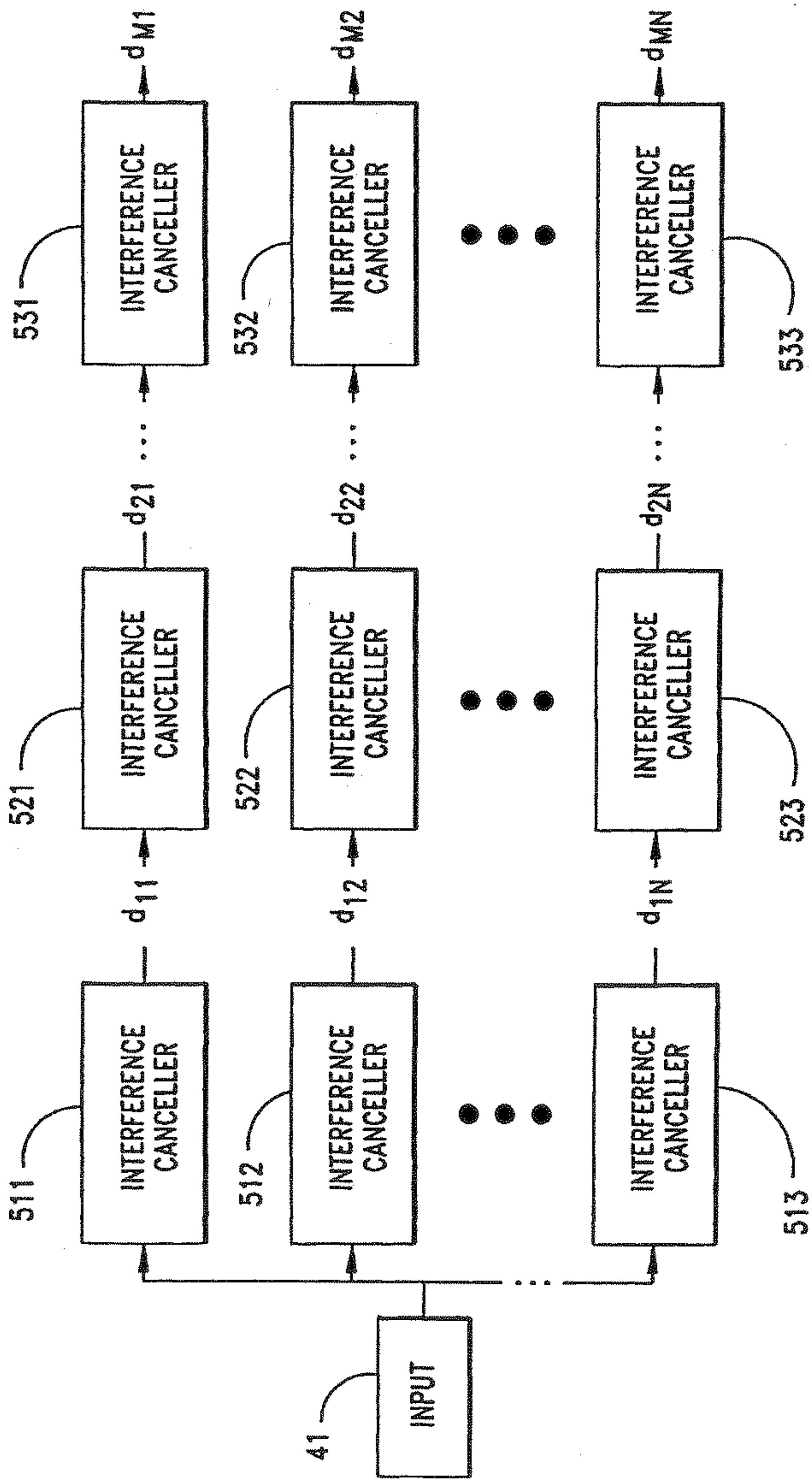
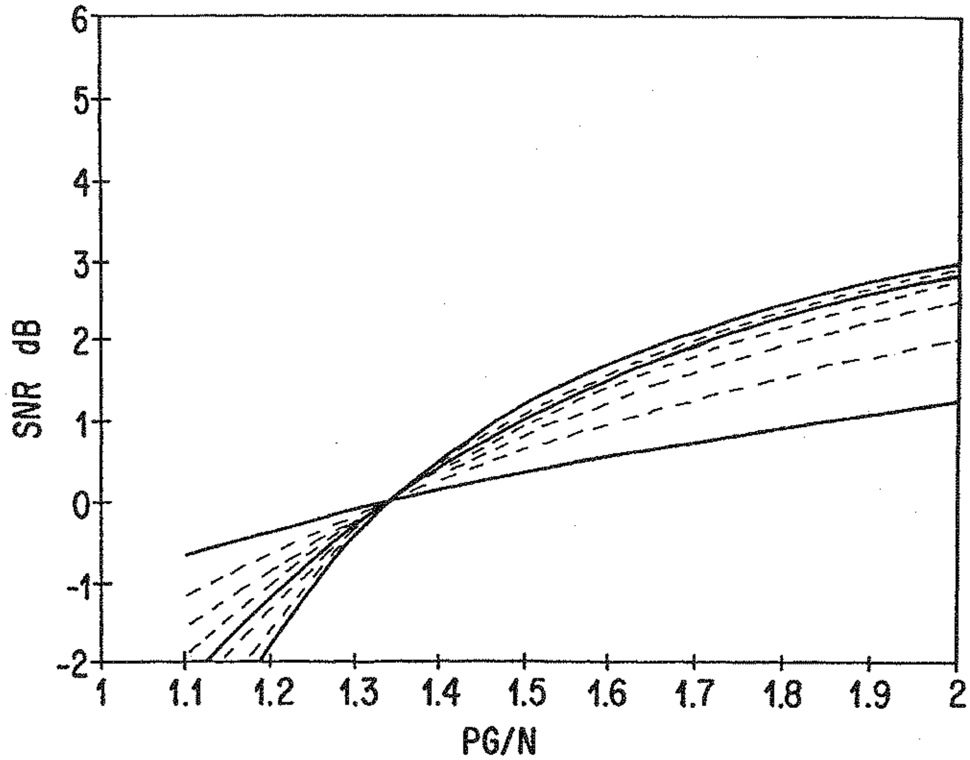
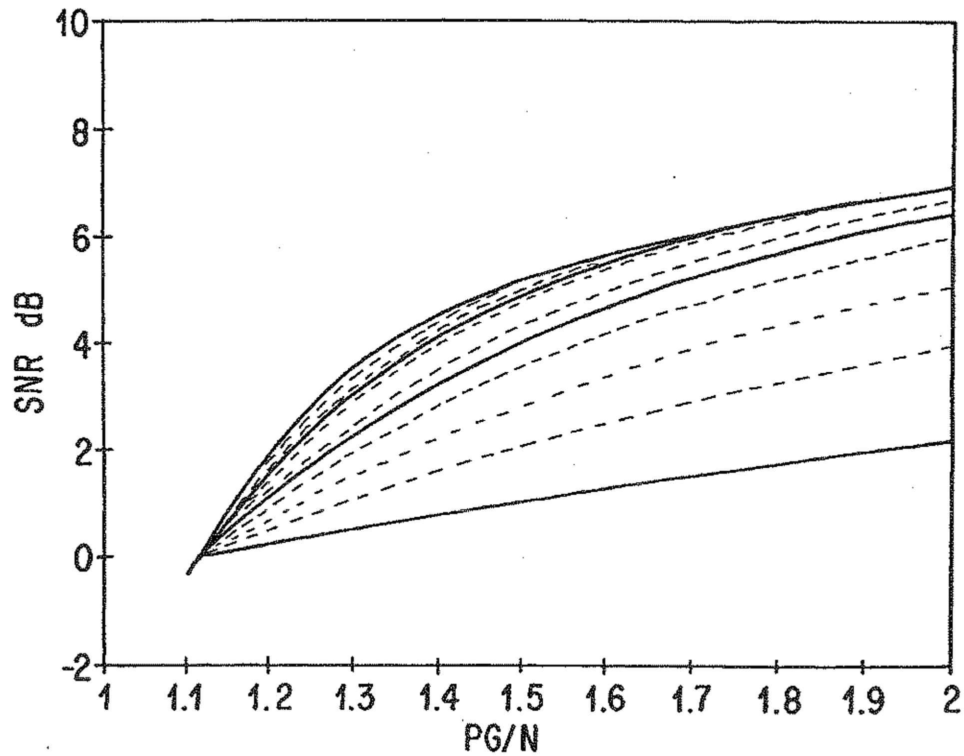

INPUT
41
INTERFERENCE CANCELLER
511
512
513
521
522
523
531
532
533
d_{11}
d_{12}
d_{1N}
d_{21}
d_{22}
d_{2N}
d_{M1}
d_{M2}
d_{MN}

FIG. 5



6
5
4
3
2
1
0
-1
-2
SNR dB
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

FIG.6



10
8
6
4
2
0
-2
SNR dB
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

FIG.7

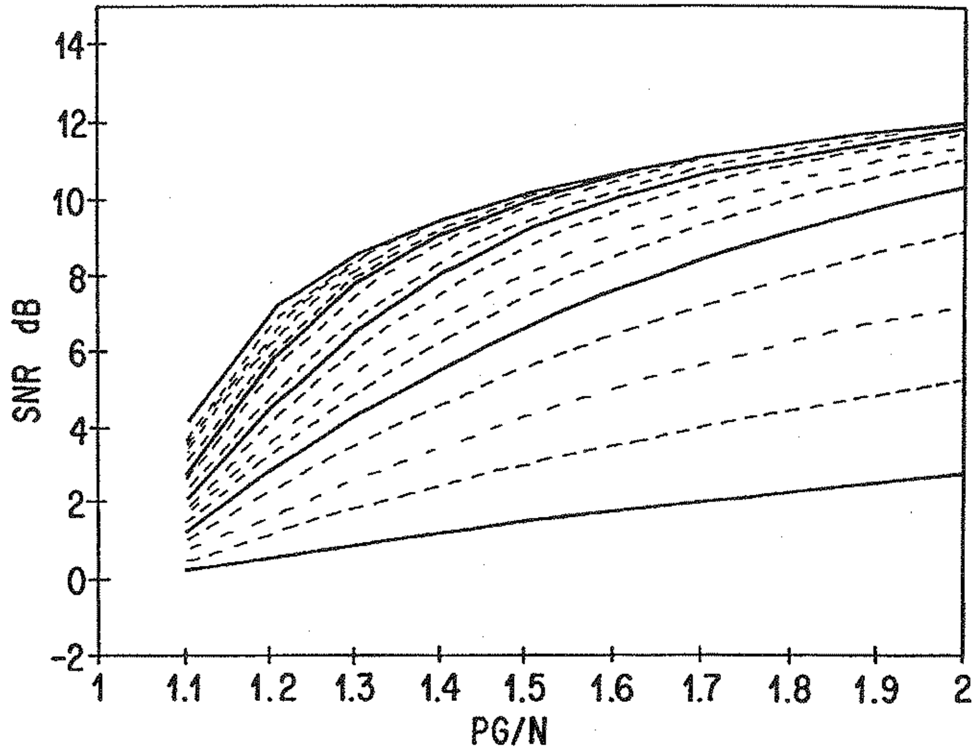

14
12
10
8
6
4
2
0
-2
SNR dB
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

FIG. 8

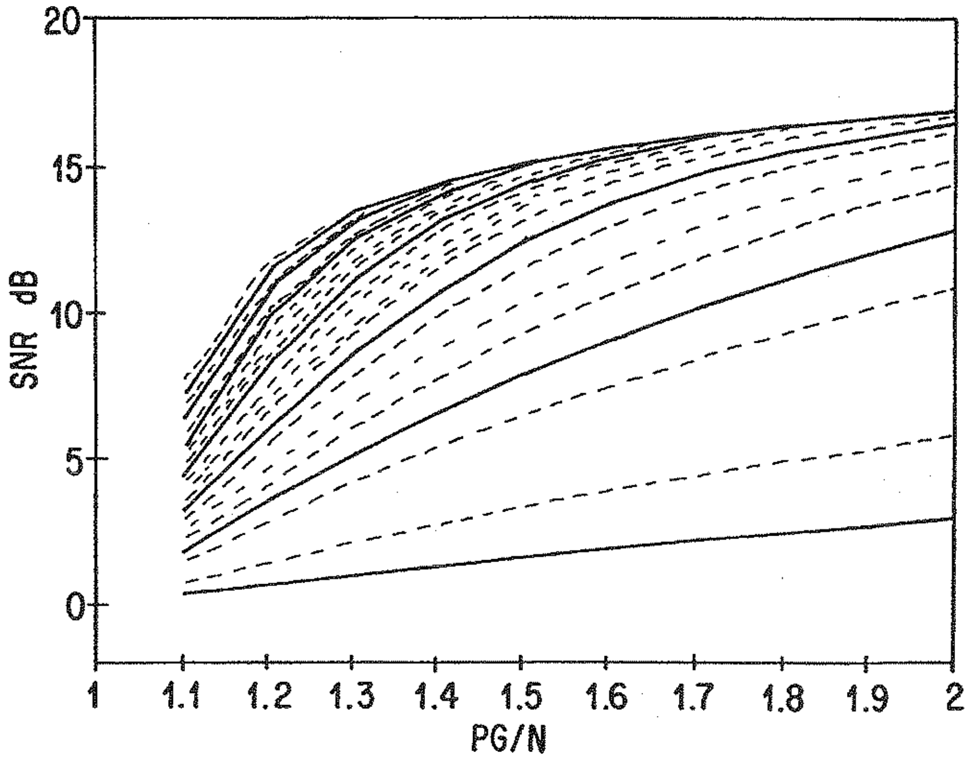

20
15
10
5
0
SNR dB
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

FIG. 9

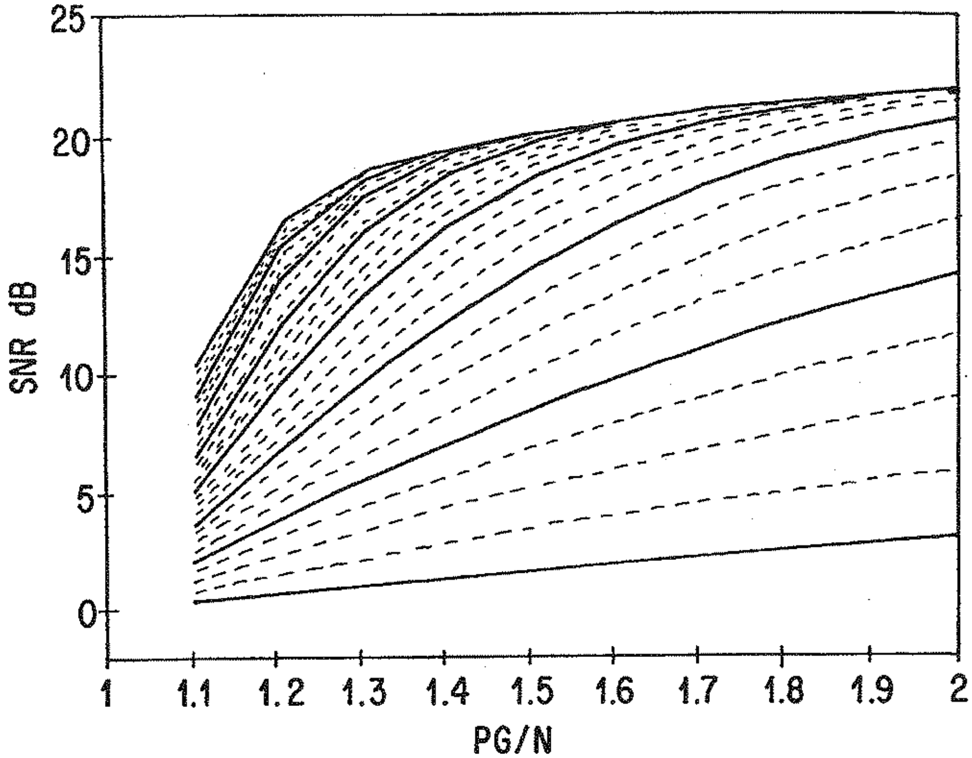

25
20
15
10
5
0
SNR dB
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

FIG.10

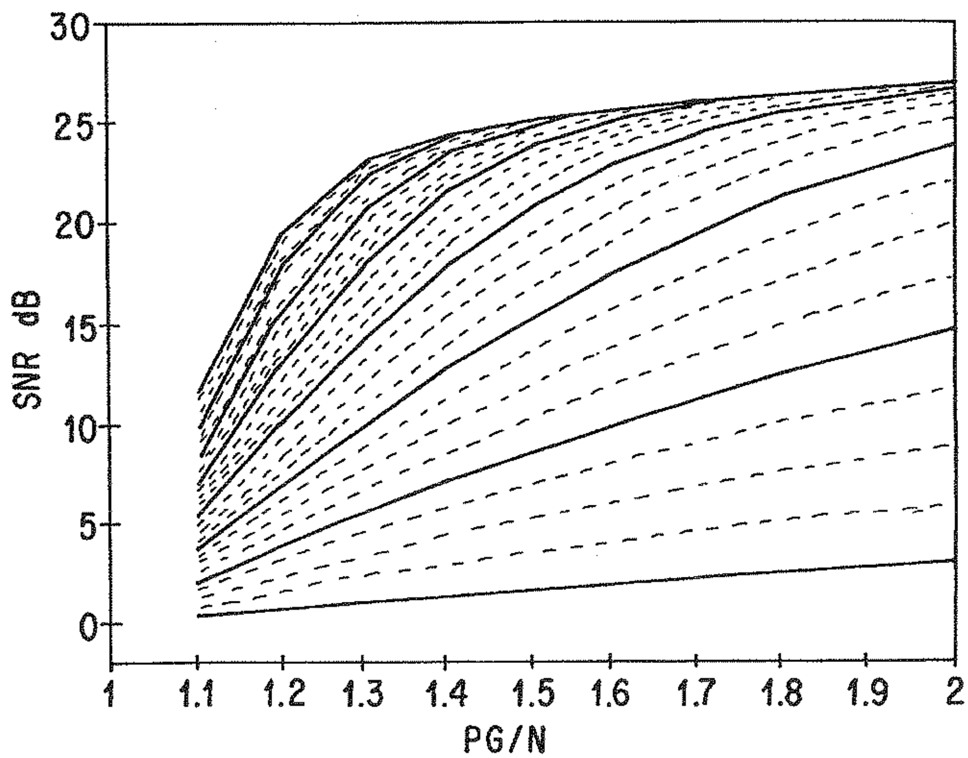

30
25
20
15
10
5
0
SNR dB
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

FIG.11

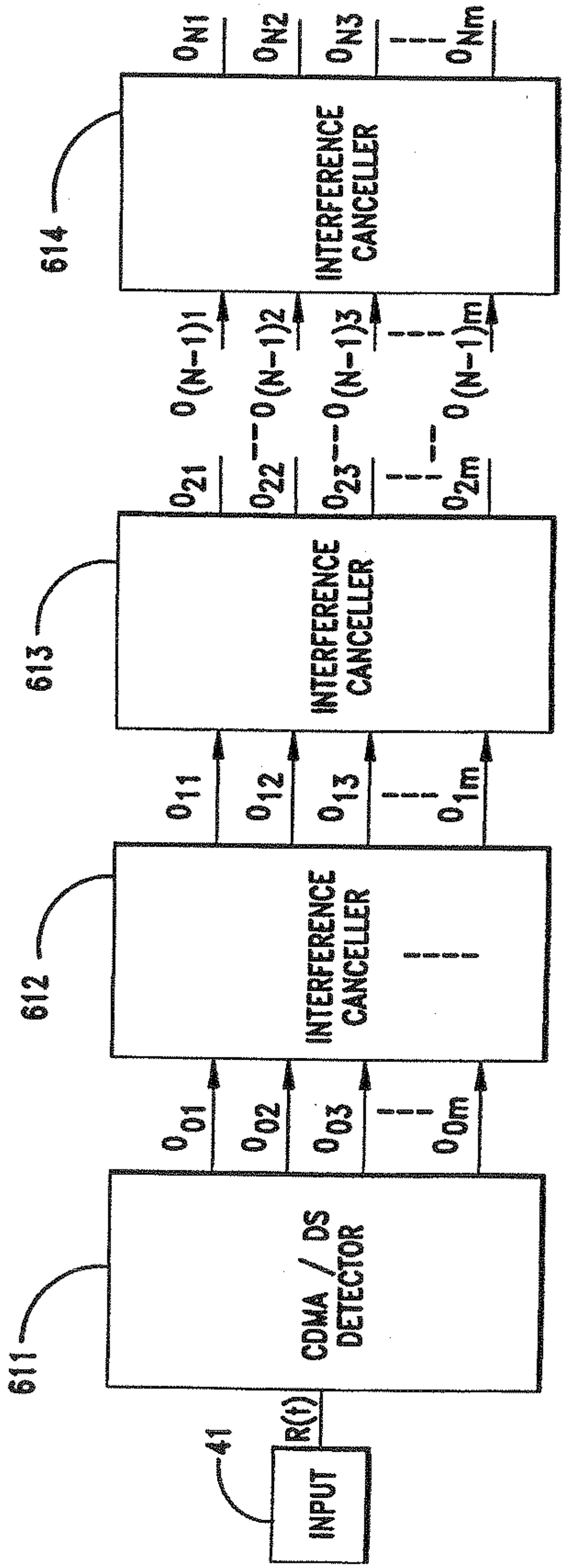

INPUT
41
R(t)
611
CDMA / DS DETECTOR
O_{01}
O_{02}
O_{03}
O_{0m}
612
INTERFERENCE CANCELLER
O_{11}
O_{12}
O_{13}
O_{1m}
613
INTERFERENCE CANCELLER
O_{21}
O_{22}
O_{23}
O_{2m}
$O_{(N-1)1}$
$O_{(N-1)2}$
$O_{(N-1)3}$
$O_{(N-1)m}$
614
INTERFERENCE CANCELLER
O_{N1}
O_{N2}
O_{N3}
O_{Nm}

FIG. 12

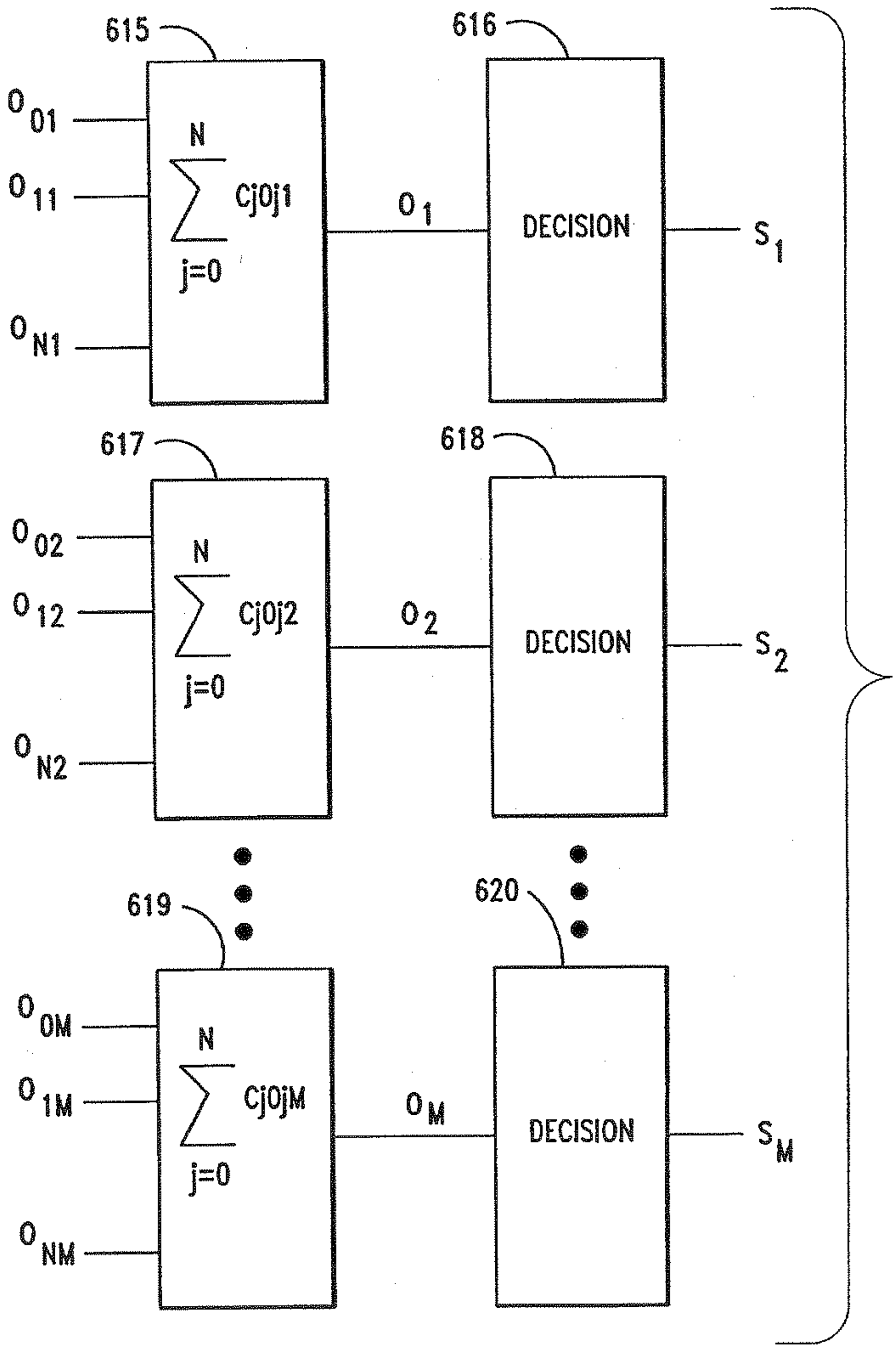

615
616
O_{01}
O_{11}
O_{N1}
$\sum_{j=0}^{N} CjOj1$
O_1
DECISION
S_1
617
618
O_{02}
O_{12}
O_{N2}
$\sum_{j=0}^{N} CjOj2$
O_2
DECISION
S_2
619
620
O_{0M}
O_{1M}
O_{NM}
$\sum_{j=0}^{N} CjOjM$
O_M
DECISION
S_M

FIG. 13

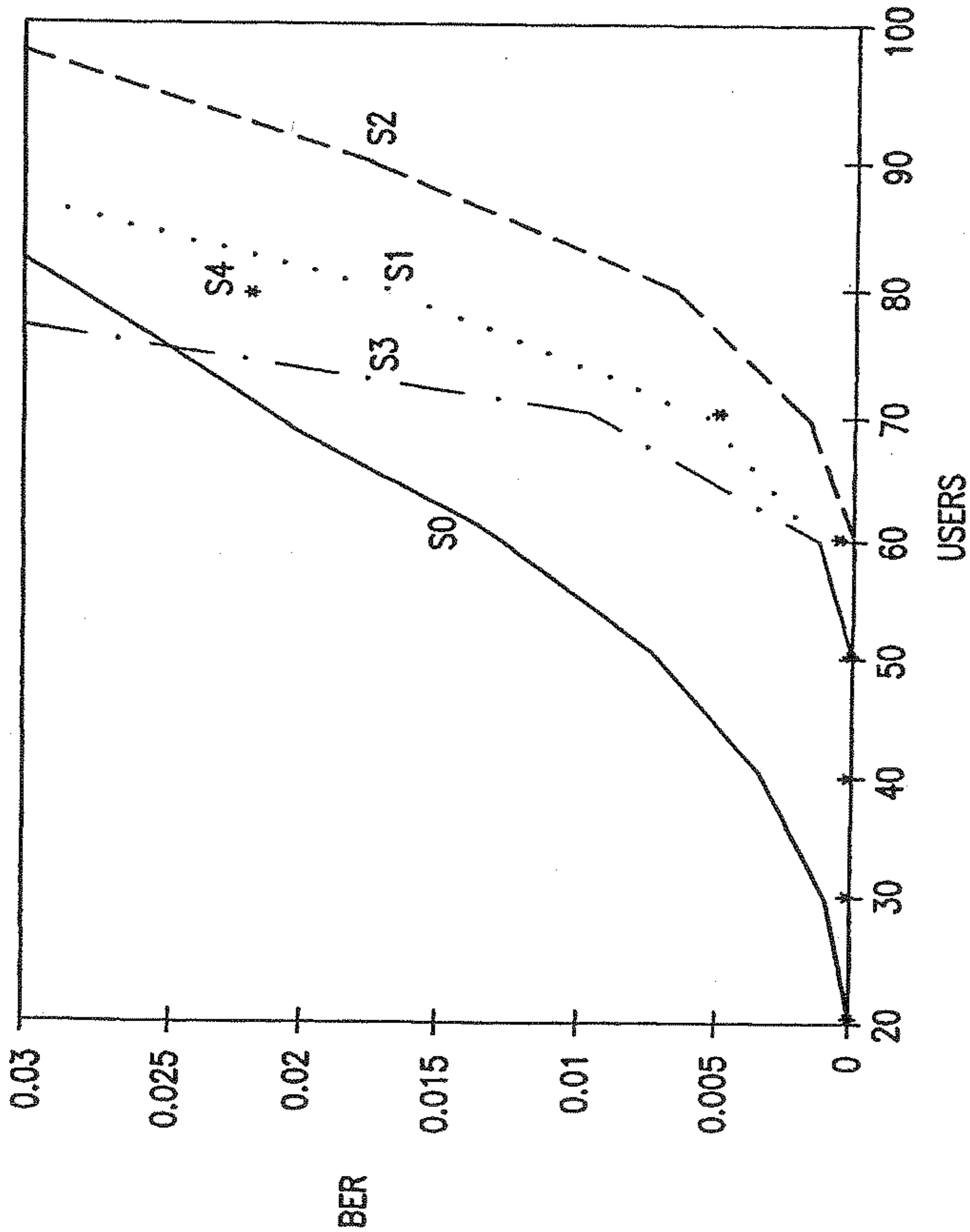

BER
0.03
0.025
0.02
0.015
0.01
0.005
0
20
30
40
50
60
70
80
90
100
USERS
S0
S1
S2
S3
S4

FIG. 14

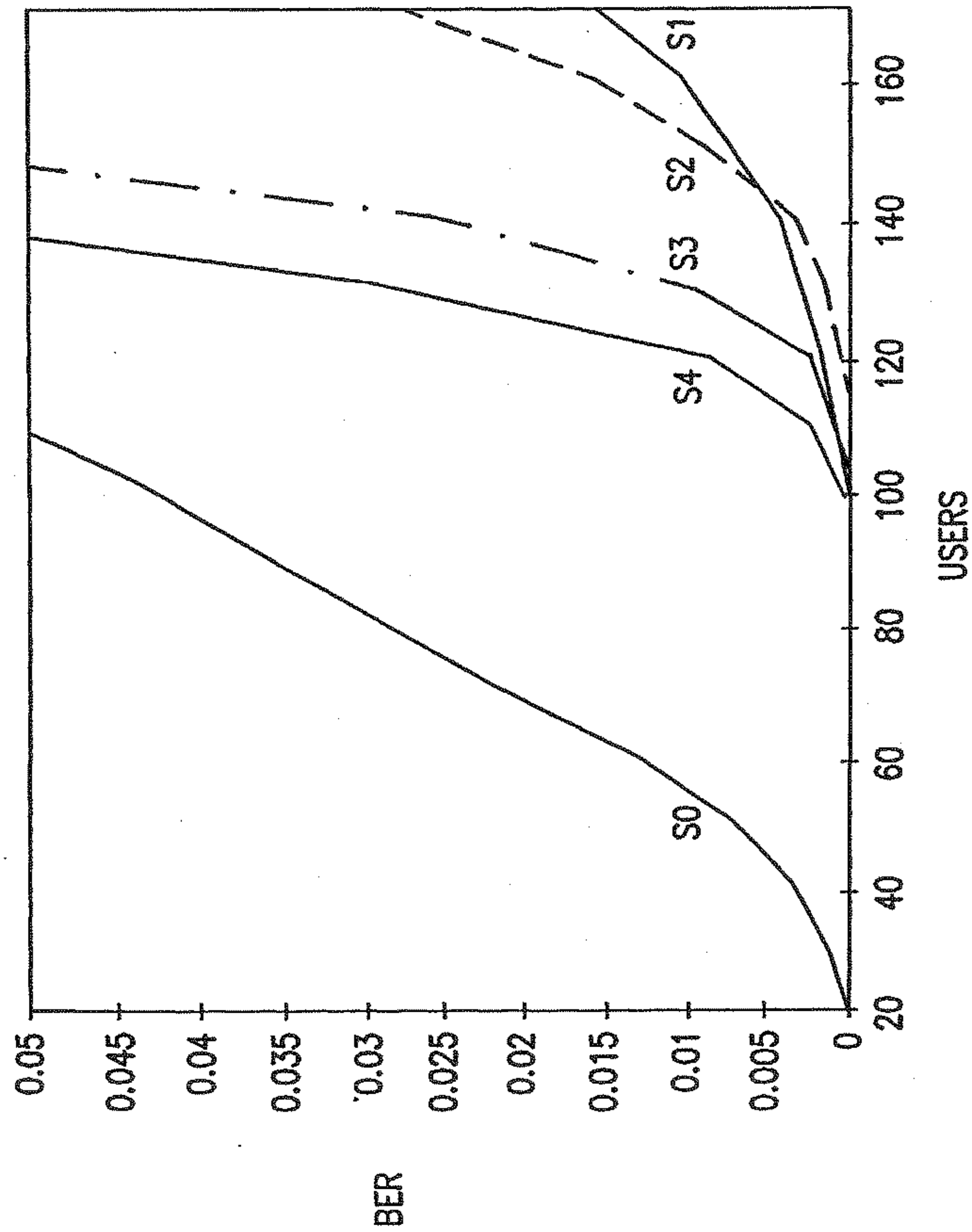

BER
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
USERS
20
40
60
80
100
120
140
160
S0
S1
S2
S3
S4

FIG. 15

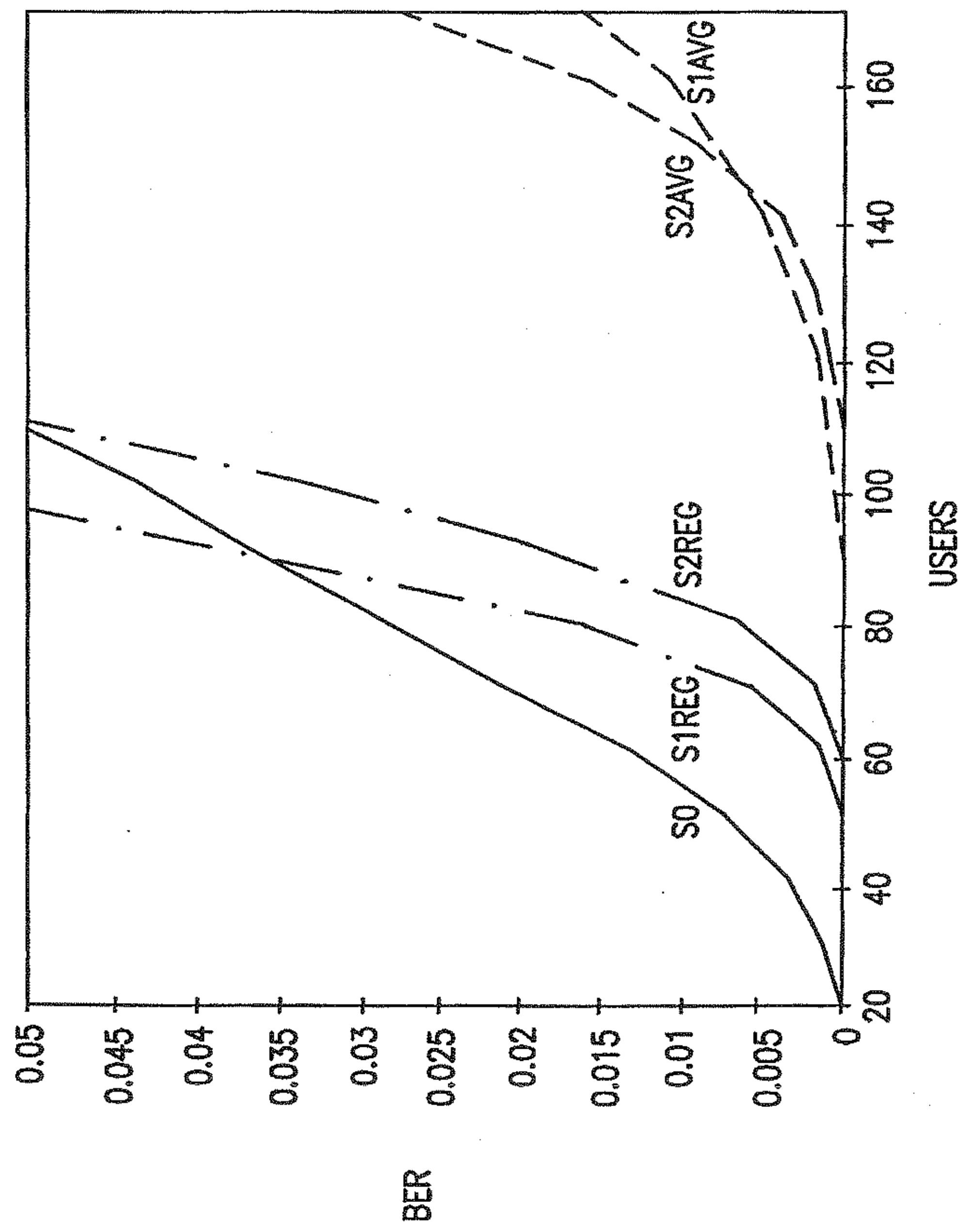

BER
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
USERS
20
40
60
80
100
120
140
160
S0
S1REG
S2REG
S2AVG
S1AVG

FIG. 16

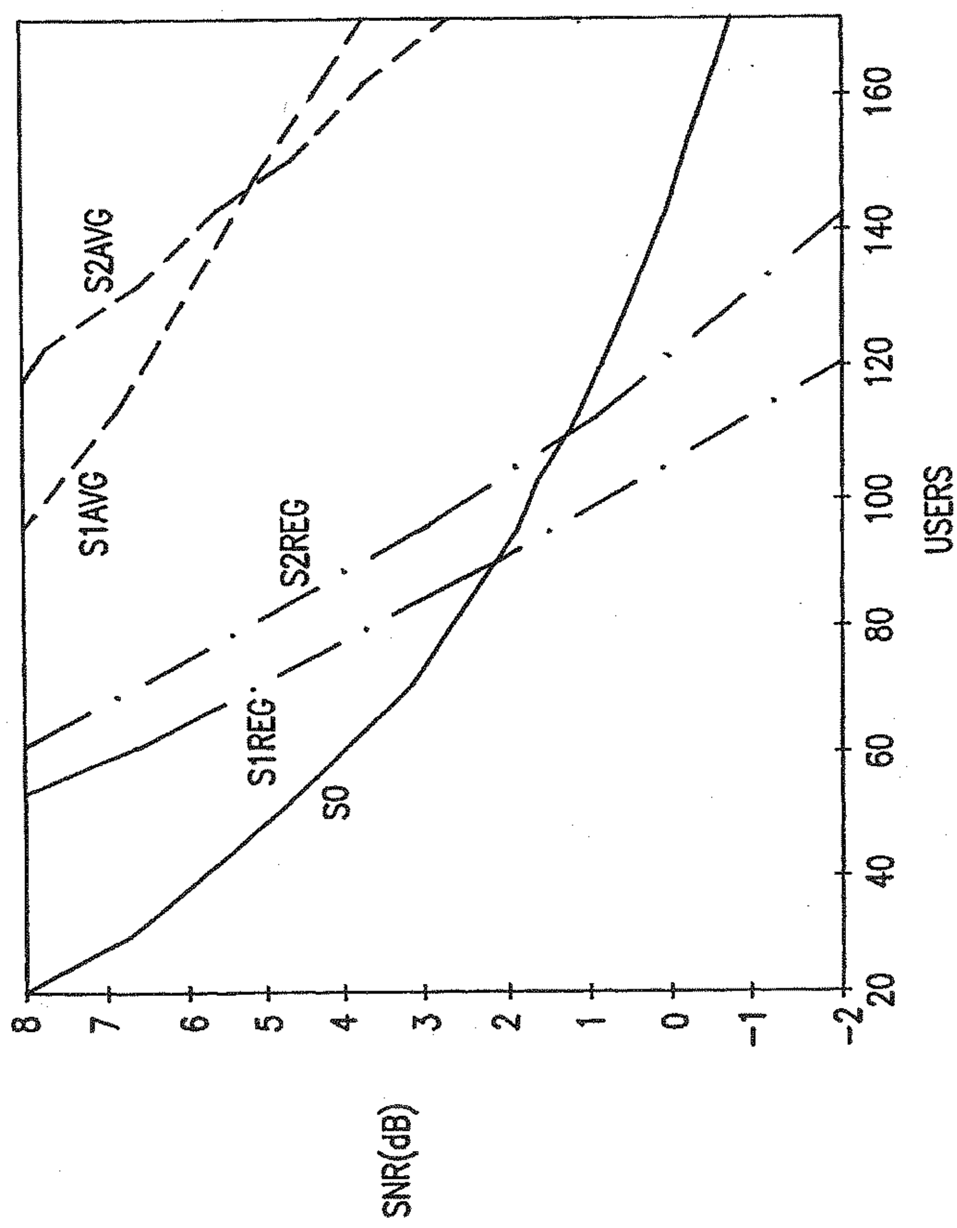

S2AVG
S1AVG
S2REG
S1REG
S0
SNR(dB)
8
7
6
5
4
3
2
1
0
−1
−2
USERS
20
40
60
80
100
120
140
160

FIG. 17

SPREAD SPECTRUM CDMA SUBTRACTIVE INTERFERENCE CANCELER SYSTEM

RELATED APPLICATIONS

This patent application is a continuation application of U.S. patent application Ser. No. 08/654,994, filed May 29, 1996, now U.S. Pat. No. 5,719,852 issued on Feb. 17, 1998 which is a continuation application of U.S. patent application Ser. No. 08/279,477, filed Jul. 26, 1994, now U.S. Pat. No. 5,553,062 issued on Sep. 3, 1996, which is a continuation-in-part of U.S. patent application Ser. No. 08/051,017, filed Apr. 22, 1993, now U.S. Pat. No. 5,363,403 issued on Nov. 8, 1994.

BACKGROUND OF THE INVENTION

This invention relates to spread-spectrum communications, and more particularly to an interference canceler and method for reducing interference in a direct sequence, code division multiple access receiver.

DESCRIPTION OF THE RELEVANT ART

Direct sequence, code division multiple access, spread-spectrum communications systems are capacity limited by interference caused by other simultaneous users. This is compounded if adaptive power control is not used, or is used but is not perfect.

Code division multiple access is interference limited. The more users transmitting simultaneously, the higher the bit error rate (BER). Increased capacity requires forward error correction (FEC) coding, which is turn, increases the data rate and limits capacity.

SUMMARY OF THE INVENTION

A general object of the invention is to reduce noise resulting from N−1 interfering signals in a direct sequence, spread-spectrum code division multiple access receiver.

The present invention, as embodied and broadly described herein, provides a spread-spectrum code division multiple access (CDMA) interference canceler for reducing interference in a spread-spectrum CDMA receiver having N channels. Each of the N channels is spread-spectrum processed by a distinct chip-code signal. The chip-code signal, preferably, is derived from a distinct pseudo-noise (PN) sequence, which may be generated from a distinct chip codeword. The interference canceler partially cancels N−1 interfering CDMA channels, and provides a signal-to-noise ratio (SNR) improvement of approximately N/PG, where PG is the processing gain. Processing gain is the ratio of the chip rate divided by the bit rate. By canceling or reducing interference, the SNR primarily may be due to thermal noise, and residual, interference-produced noise. Thus, the SNR may increase, lowering the BER, which reduces the demand for a FEC encoder/decoder.

The interference canceler, for a particular channel, includes a plurality of despreading means, a plurality of spread-spectrum-processing means, subtracting means, and channel-despreading means. Using a plurality of chip-code signals, the plurality of despreading means despreads the spread-spectrum CDMA signals as a plurality of despread signals, respectively. The plurality of spread-spectrum-processing means uses a timed version of the plurality of chip-code signals, for spread-spectrum processing the plurality of despread signals, respectively, with a chip-code signal corresponding to a respective despread signal. The timed version of a chip-code signal may be generated by delaying the chip-code signal from a chip-code-signal generator. Alternatively, a matched filter may detect a particular PN sequence in the spread-spectrum CDMA signal. A chip-code signal generator may use the detected signal from the matched filter to trigger a timed version of the chip-code signal.

For receiving a particular CDMA channel using an i^{th} chip-code signal, the subtracting means subtracts from the spread-spectrum CDMA signal, each of the N−1 spread-spectrum-processed-despread signals, thereby generating a subtracted signal. The N−1 spread-spectrum-processed-despread signals do not include the spread-spectrum-processed-despread signal of the i^{th} channel corresponding to the i^{th} chip-code signal. The channel-despreading means despreads the subtracted signal with the i^{th} chip-code signal.

The present invention also includes a method for reducing interference in a spread-spectrum CDMA receiver having N channels. The method comprises the steps of despreading, using a plurality of chip-code signals, the spread-spectrum CDMA signal as a plurality of despread signals, respectively; spread-spectrum processing, using a timed version of the plurality of chip-code signals, the plurality of despread signals, respectively, with a chip-code signal corresponding to a respective despread signal; subtracting from the spread-spectrum CDMA signal, each of the N−1 spread-spectrum-processed-despread signals, with the N−1 spread-spectrum-processed-despread signals *not including* a spread-spectrum-processed despread signal of the i^{th} channel, thereby generating a subtracted signal; and, despreading the subtracted signal having the i^{th} chip-code signal.

Additional objects and advantages of the invention are set forth in part in the description which follows, and in part are obvious from the description, or may be learned by practice of the invention. The objects and advantages of the invention also may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate preferred embodiments of the invention, and together with the description serve to explain the principles of the invention.

FIG. 1 is a block diagram of the spread-spectrum CDMA interference canceler using correlators;

FIG. 2 is a block diagram of the spread-spectrum CDMA interference canceler for processing multiple channels using correlators;

FIG. 3 is a block diagram of the spread-spectrum CDMA interference canceler using matched filters;

FIG. 4 is a block diagram of the spread-spectrum CDMA interference canceler for processing multiple channels using matched filters;

FIG. 5 is a block diagram of the spread-spectrum CDMA interference canceler having multiple iterations for processing multiple channels;

FIG. 6 illustrates theoretical performance characteristic for E_b/η=6 dB;

FIG. 7 illustrates theoretical performance characteristic for E_b/η=10 dB;

FIG. 8 illustrates theoretical performance characteristic for E_b/η=15 dB;

FIG. 9 illustrates theoretical performance characteristic for E_b/β=20 dB;

FIG. 10 illustrates theoretical performance characteristic for E_b/η=25 dB;

FIG. 11 illustrates theoretical performance characteristic for E_b/η=30 dB;

FIG. 12 is a block diagram of interference cancelers connected together;

FIG. 13 is a block diagram combining the outputs of the interference cancelers of FIG. 12;

FIG. 14 illustrates simulation performance characteristics for asynchronous, PG=100, Equal Powers, EbN=30 B;

FIG. 15 illustrates simulation performance characteristics for asynchronous, PG=100, Equal Powers, EbN=30 dB;

FIG. 16 illustrates simulation performance characteristics for asynchronous, PG=100, Equal Powers, EbN=30 dB; and

FIG. 17 illustrates simulation performance characteristics for asynchronous, PG=100, Equal Powers, EbN=30 db.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference now is made in detail to the present preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings, wherein like reference numerals indicate like elements throughout the several views.

In the exemplary arrangement shown in FIG. 1, a spread-spectrum code division multiple access (CDMA) interference canceler is provided for reducing interference in a spread-spectrum CDMA receiver having N channels. The present invention also works on a spread-spectrum code division multiplexed (CDMA) system. Accordingly, without loss of generality, the term spread-spectrum CDMA signal, as used herein, includes spread-spectrum CDMA signals and spread-spectrum CDM signals. In a personal communications service, the interference canceler may be used at a base station or in a remote unit such as a handset.

FIG. 1 illustrates the interference canceler for the first channel, defined by the first chip-code signal. The interference canceler includes a plurality of despreading means, a plurality of timing means, a plurality of spread-spectrum-processing means, subtracting means, and first channel-despreading means.

Using a plurality of chip-code signals, the plurality of despreading means despreads the received spread-spectrum CDMA signals as a plurality of despread signals, respectively. In FIG. 1 the plurality of despreading means is shown as first despreading means, second despreading means, through N^{th} despreading means. The first despreading means includes a first correlator, which is embodied, by way of example, as a first mixer **51**, first chip-code-signal generator **52**, and a first integrator **54**. The first integrator **54** alternatively may be a first lowpass filter or a first bandpass filter. The first mixer **51** is coupled between the input **41** and the first chip-code-signal generator **52** and the first integrator **54**.

The second despreading means includes a second correlator, which is embodied, by way of example, as second mixer **61**, second chip-code-signal generator **62** and second integrator **64**. The second integrator **64** alternatively may be a second lowpass filter or a second bandpass filter. The second mixer **61**, is coupled between the input **41**, the second chip-code-signal generator **62**, and the second integrator **64**.

The N^{th} despreading means is depicted as an N^{th} correlator shown, by way of example, as N^{th} mixer **71**, and N^{th} chip-code-signal generator **72**, and N^{th} integrator **74**. The N^{th} integrator **74** alternatively may be an N^{th} lowpass filter or an N^{th} bandpass filter. The N^{th} mixer **71** is coupled between the input **41**, the N^{th} chip-code-signal generator **72** and the N^{th} integrator **74**.

As is well known in the art, the first through N^{th} despreading means may be embodied as any device which can despread a channel in a spread-spectrum signal.

The plurality of timing means may be embodied as a plurality of delay devices **53**, **63**, **73**. A first delay device **53** has a delay time T, which is approximately the same as the integration time T_b of first integrator **54**, or time constant of the first lowpass filter or first bandpass filter. A second delay device **63** has a time delay T, which is approximately the same as the integration time T_b of second integrator **64**, or time constant of the second lowpass filter or second bandpass filter. Similarly, the N^{th} delay device **73** has a time delay T, which is approximately the same as the integration time T_b of N^{th} integrator **74**, or time constant of the N^{th} lowpass filter or N^{th} bandpass filter. Typically, the integration times of the first integrator **54**, second integrator **64** through N^{th} integrator **74** are the same. If lowpass filters are used, then typically the time constants of the first lowpass filter, second lowpass filter through N^{th} lowpass filter are the same. If bandpass filters are used, then the time constants of the first bandpass filter, second bandpass filter through N^{th} bandpass filter are the same.

The plurality of spread-spectrum-processing means regenerators each of the plurality of despread signals as a plurality of spread-spectrum signals. The plurality of spread-spectrum-processing means uses a timed version, i.e. delayed version, of the plurality of chip-code signals, for spread-spectrum processing the plurality of despread signals, respectively, with a chip-code signal corresponding to a respective despread signal. The plurality of spread-spectrum-processing means is shown, by way of example, as a first processing mixer **55**, a second processing mixer **65**, through an N^{th} processing mixer **75**. The first processing mixer **55** is coupled to the first integrator **54**, and through a first delay device **53** to the first chip-code-signal generator **52**. The second processing mixer **65** is coupled to the second integrator **64**, and through the second delay device **63** to the second chip-code-signal generator **62**. The N^{th} processing mixer **75** is coupled to the N^{th} integrator **74** through the delay device **73** to the N^{th} chip-code-signal generator **72**.

For reducing interference to a channel using an i^{th} chip-code signal of the spread-spectrum CDMA signal, the subtracting means subtracts, from the spread-spectrum CDMA signal, each of the N−1 spread-spectrum-processed-despread signals not corresponding to the i^{th} channel. The subtracting means thereby generates a subtracted signal. The substracting means is shown as a first subtractor **150**. The first subtractor **150** is shown coupled to the output of the second processing mixer **65**, through the N^{th} processing mixer **75**. Additionally, the first subtractor **150** is coupled through a main delay device **48** to the input **41**.

The i^{th} channel-despreading means despreads the subtracted signal with the i^{th} chip-code signal as the i^{th} channel. The first channel-despreading means is shown as a first channel mixer **147**. The first channel mixer **147** is coupled to the first delay device **53**, and to the first subtractor **150**. The first channel integrator **146** is coupled to the first channel mixer **147**.

The first chip-code-signal generator **52**, the second chip-code-signal generator **62**, through the N^{th} chip-code signal generator **72** generate a first chip-code signal, a second chip-code signal, through a N^{th} chip-code signal, respectively. The term "chip-code signal" is used herein to mean the spreading signal of a spread-spectrum signal, as is well known in the art. Typically the chip-code signal is generated from a pseudorandom (PN) sequence. The first chip-code

signal, the second chip code signal, through the N^{th} chip-code signal might be generated from a first PN sequence, a second PN sequence, through a N^{th} PN sequence, respectively. The first PN sequence is defined by or generated from a first chip codeword, the second PN sequence is defined by or generated from a second chip codeword, through the N^{th} PN sequence is defined by or generated from a N^{th} chip-codeword. Each of the first chip codeword, second chip codeword through N^{th} chip codeword is distinct, i.e. different from one another. In general, a chip codeword can be the actual sequence of a PN sequence, or used to define settings for generating the PN sequence. The settings might be the delay taps of shift registers, for example.

A first channel of a received spread-spectrum CDMA signal at input **41** is despread by first mixer **51** as a first despread signal, using the first chip-code signal generated by first chip-code-signal generator **52**. The first despread signal from the first mixer **51** is filtered through first integrator **54**. First integrator **54** integrates for a time T_b, the time duration of a symbol such as a bit. At the same time, the first chip-code signal is delayed by time T by delay device **53**. The delay time T is approximately equal to the integration time T_b plus system or component delays. Systems or component delays are usually small, compared to integration time T_b.

The delayed version of the first chip-code signal is processed with the first despread signal from the output of the first integrator **54** using the first spreading mixer **55**. The output of the first spreading mixer **55** is fed to subtractors other than first subtractor **150** for processing the second through N^{th} channels of the spread-spectrum CDMA signal.

For reducing interference to the first channel of the spread-spectrum CDMA signal, the received spread-spectrum CDMA signal is processed by the second through N^{th} despreaders as follows. The second channel of the spread-spectrum CDMA signal is despread by the second despreading means. At the second mixer **61**, a second chip-code signal, generated by the second chip-code-signal generator **62**, despreads the second channel of the spread-spectrum CDMA signal. The despread second channel is filtered through second integrator **64**. The output of the second integrator **64** is the second despread signal. The second despread signal is spread-spectrum processed by second processing mixer **65** by a delayed version of the second chip-code signal. The second chip-code signal is delayed through delay device **63**. The delay device **63** delays the second chip-code signal by time T. The second channel mixer **65** spread-spectrum processes a timed version, i.e. delayed version, of the second chip-code signal with the filtered version of the second spread-spectrum channel from second integrator **64**. The term "spread-spectrum process" as used herein includes any method for generating a spread-spectrum signal by mixing or modulating a signal with a chip-code signal. Spread-spectrum processing may be done by product devices, EXCLUSIVE-OR gates, matched filters, or any other device or circuit as is well known in the art.

Similarly, the N^{th} channel of the spread-spectrum CDMA signal is despread by the N^{th} despreading means. Accordingly, the received spread-spectrum CDMA signal has the N^{th} channel despread by N^{th} mixer **61**, by mixing the spread-spectrum CDMA signal with the N^{th} chip-code signal from N^{th} chip-code-signal generator **72**. The output of the N^{th} mixer **71** is filtered by N^{th} integrator **74**. The output of the N^{th} integrator **74**, which is the N^{th} despread signal, is a despread and filtered version of the N^{th} channel of the spread-spectrum CDMA signal. The N^{th} despread signal is spread-spectrum processed by a delayed version of the N^{th} chip-code signal. The N^{th} chip-code signal is delayed through N^{th} delay device **73**. The N^{th} processing mixer **75** spread-spectrum processes the timed version, i.e. a delayed version, of the N^{th} chip-code signal with the N^{th} despread signal.

At the first subtractor **150**, each of the outputs of the second processing mixer **63** through the N^{th} processing mixer **75** is subtracted from a timed version, i.e. a delayed version, of the spread-spectrum CDMA signal from input **41**. The delay of the spread-spectrum CDMA signal is timed through the first main delay device **48**. Typically, the delay of the first main delay device **48** is time T, which is approximately equal to the integration time of the first integrator **54** through N^{th} integrator **74**.

At the output of the first subtractor **150**, is generated a first subtracted signal. The first subtracted signal, for the first channel of the spread-spectrum CDMA signal, is defined herein to be the outputs from the second processing mixer **65** through N^{th} processing mixer **75**, subtracted from the delayed version of the spread-spectrum CDMA signal. The second subtracted signal through N^{th} subtracted signal are similarly defined.

The delayed version of the first chip-code signal from the output of first delay device **53** is used to despread the output of the first subtractor **150**. Accordingly, the first subtracted signal is despread by the first chip-code signal by first channel mixer **147**. The output of the first channel mixer **147** is filtered by first channel integrator **147**. This produces an output estimate d_1 of the first channel of the spread-spectrum CDMA signal.

As illustratively shown in FIG. **2**, a plurality of subtractors **150, 250, 350, 450** can be coupled appropriately to the input **41** and to a first spreading mixer **55**, second spreading mixer **65**, *third spreading mixer*, through an N^{th} spreading mixer **75** of FIG. **1**. The plurality of subtractors **150, 250, 350, 450** also are coupled to the main delay device **48** from the input **41**. This arrangement can generate a first subtracted signal from the first subtractor **150**, a second subtracted signal from the second subtractor **250**, a third subtracted signal from the third subtractor **350**, through an N^{th} subtracted signal from an N^{th} subtractor **450**.

The outputs of the first subtractor **150**, second subtractor **250**, third subtractor **350**, through the N^{th} subtractor **450** are each coupled to a respective first channel mixer **147**, second channel mixer **247**, third channel mixer **347**, through N^{th} channel mixer **447**. Each of the channel mixers is coupled to a delayed version of the first chip-code signal, $g_1(t-T)$, second chip-code signal, $g_2(t-T)$, third chip-code signal, $g_3(t-T)$, through N^{th} chip-code signal, $g_N(t-T)$. The outputs of each of the respective first channel mixer **147**, second channel mixer **247**, third channel mixer **347**, through N^{th} channel mixer **447** are coupled to a first channel integrator **146**, second channel integrator **246**, third channel integrator **346** through N^{th} channel integrator **446**, respectively. At the output of each of the channel integrators is produced an estimate of the respective first channel d_1, second channel d_2, third channel d_3, through N^{th} channel d_N.

Referring to FIG. **1**, use of the present invention is illustrated for the first channel of the spread-spectrum CDMA signal, with the understanding that the second through N^{th} CDMA channels work similarly. A received spread-spectrum CDMA signal at input **41** is delayed by delay device **48** and fed to the first subtractor **150**. The spread-spectrum CDMA signal has the second channel through N^{th} channel despread by second mixer **61** using the second chip-code signal, through the N^{th} mixer **71** using the

N^{th} chip-code signal. The respective second chip-code signal through the N^{th} chip-code signal are generated by the second chip-code-signal generator **62** through the N^{th} chip-code-signal generator **72**. The second channel through N^{th} channel are despread and filtered through the second integrator **64** through the N^{th} integrator **74**, respectively. The despreading removes, partially or totally, the non-despread channels at the outputs of each of the second integrator **64** through N^{th} integrator **74**.

In a preferred embodiment, each of the chip-code signal used for the first chip-code-signal generator **52**, second chip-code-signal generator **62** through the N^{th} chip-code-signal generator **72**, are orthogonal to each other. Use of chip-code signals having orthogonality however, is not required for operation of the present invention. When using orthogonal chip-code signals, the despread signals have the respective channel plus noise at the output of each of the integrators. With orthogonal chip-code signals, theoretically the mixers remove channels orthogonal to the despread channel. The respective channel is spread-spectrum processed by the respective processing mixer.

At the output of the second processing mixer **65** through the N^{th} processing mixer **75** is a respread version of the second channel through the N^{th} channel, plus noise components contained therein. Each of the second channel through N^{th} channel is then subtracted from the received spread-spectrum CDMA signal by the first subtractor **150**. The first subtractor **150** produces the first subtracted signal. The first subtracted signal is despread by a delayed version of the first chip-code signal by first channel mixer **147**, and filtered by first channel filter **146**. Accordingly, prior to despreading the first channel of the spread-spectrum CDMA signal, the second through N^{th} channels plus noise components aligned with these channels are subtracted from the received spread-spectrum CDMA signal. As illustratively shown in FIG. **3**, an alternative embodiment of the spread-spectrum CDMA interference canceler includes a plurality of first despreading means, a plurality of spread-spectrum-processing means, subtracting means, and second despreading means. In FIG. **3**, the plurality of despreading means is shown as first despreading means, second despreading means through N^{th} despreading means. The first despreading means is embodied as a first matched filter **154**. The first matched filter **154** has an impulse response matched to the first chip-code signal, which is used to spread-spectrum process and define the first channel of the spread-spectrum CDMA signal. The first matched filter **154** is coupled to the input **41**.

The second despreading means is shown as second matched filter **164**. The second matched filter **164** has an impulse response matched to the second chip-code signal, which is used to spread-spectrum process and define the second channel of the spread-spectrum CDMA signal. The second matched filter **164** is coupled to the input **41**.

The N^{th} despreading means is shown as an N^{th} matched filter **174**. The N^{th} matched filter has an impulse response matched to the N^{th} chip-code signal, which is used to spread-spectrum process and define the N^{th} channel of the spread-spectrum CDMA signal. The N^{th} matched filter is coupled to the input **41**.

The term matched filter, as used herein, includes any type of matched filter that can be matched to a chip-code signal. The matched filter may be a digital matched filter or analog matched filter. A surface acoustic wave (SAW) device may be used at a radio frequency (RF) or intermediate frequency (IF). Digital signal processors and application specific integrated circuits (ASIC) having matched filters may be used at RF, IF or baseband frequency.

In FIG. **3**, the plurality of spread-spectrum-processing means is shown as the first processing mixer **55**, the second processing mixer **65**, through the N^{th} processing mixer **75**. The first processing mixer **55** may be coupled through a first adjustment device **97** to the first chip-code-signal generator **52**. The second processing mixer **65** may be coupled through the second adjustment device **98** to the second chip-code-signal generator **62**. The N^{th} processing mixer **75** may be coupled through the N^{th} adjustment device **99** to the N^{th} chip-code-signal generator **72**. The first adjusting device **97**, second adjustment device **98** through N^{th} adjustment device **99** are optional, and are used as an adjustment for aligning the first chip-code signal, second chip-code signal through N^{th} chip-code signal with the first despread signal, second despread signal through N^{th} despread signal, outputted from the first matched filter **154**, second matched filter **164** through N^{th} matched filter **174**, respectively.

The subtracting means is shown as the first subtractor **150**. The first subtractor **150** is coupled to the output of the second processing mixer **65**, through the N^{th} processing mixer **75**. Additionally, the first subtractor **150** is coupled through the main delay device **48** to the input **41**.

The first channel-despreading means is shown as a first channel-matched filter **126**. The first channel-matched filter **126** is coupled to the first subtractor **150**. The first channel-matched filter **126** has an impulse response matched to the first chip-code signal.

A first channel of a received spread-spectrum CDMA signal, at input **41**, is despread by first matched filter **154**. The first matched filter **154** has an impulse response matched to the first chip-code signal. The first chip-code signal defines the first channel of the spread-spectrum CDMA signal, and is used by the first chip-code-signal generator **52**. The first chip-code signal may be delayed by adjustment time τ by adjustment device **97**. The output of the first matched filter **154** is spread-spectrum processed by the first processing mixer **55** with the first chip-code signal. The output of the first processing mixer **55** is fed to subtractors other than the first subtractor **150** for processing the second channel through the N^{th} channel of the spread-spectrum CDMA signals.

For reducing interference to the first spread-spectrum channel, the received spread-spectrum CDMA signal is processed by the second despreading means through N^{th} despreading means as follows. The second matched filter **164** has an impulse response matched to the second chip-code signal. The second chip-code signal defines the second channel of the spread-spectrum CDMA signal, and is used by the second chip-code-signal generator **62**. The second matched filter **164** despreads the second channel of the spread-spectrum CDMA signal. The output of the second matched filter **164** is the second despread signal. The second despread signal triggers second chip-code-signal generator **62**. The second despread signal also is spread-spectrum processed by second processing mixer **65** by a timed version of the second chip-code signal. The timing of the second chip-code signal triggers the second despread signal from the second matched filter **164**.

Similarly, the N^{th} channel of the spread-spectrum CDMA signal is despread by the N^{th} despreading means. Accordingly, the received spread-spectrum CDMA signal has the N^{th} channel despread by N^{th} matched filter **174**. The output of the N^{th} matched filter **174** is the N^{th} despread signal, i.e. a despread and filtered version of the N^{th} channel of the spread-spectrum CDMA signal. The N^{th} despread signal is spread-spectrum processed by a timed version of

the N^{th} chip-code signal. The timing of the N^{th} chip-code signal is triggered by the N^{th} despread signal from the N^{th} matched filter **174**. The N^{th} processing mixer **75** spread-spectrum processes the timed version of the N^{th} chip-code signal with the N^{th} despread signal.

At the first subtractor **150**, each of the outputs of the second processing mixer **65** through the N^{th} processing mixer **75** are subtracted from a delayed version of the spread-spectrum CDMA signal from input **41**. The delay of the spread-spectrum CDMA signal is timed through delay device **48**. The time of delay device **48** is set to align the second through N^{th} spread-spectrum-processed-despread signals for subtraction from the spread-spectrum CDMA signal. This generates at the output of the first subtractor **150**, a first subtracted signal. The subtracted signal is despread by the first channel-matched filter **126**. This produces an output estimate d_1 of the first channel of the spread-spectrum CDMA signal.

As illustrated in FIG. **4**, a plurality of subtractors **150**, **250**, **350**, **450** can be coupled appropriately to the output from a first processing mixer, second processing mixer, third processing mixer, through a N^{th} processing mixer, and to a main delay device form the input. A first subtracted signal is outputted from the first subtractor **150**, a second subtracted signal is outputted form the second subtractor **250**, a third subtracted signal is outputted from the third subtractor **350**, through an N^{th} subtractor signal is outputted from the N^{th} subtractor **450**.

The output of the first subtractor **150**, second subtractor **250**, third subtractor **350**, through the N^{th} subtractor **450** are each coupled to a respective first channel-matched filter **126**, second channel-matched filter **226**, third channel-matched filter **326**, through N^{th} channel-matched filter **426**. The first channel-matched filter **126**, second channel-matched filter **226**, third channel-matched filter **326** through N^{th} channel-matched filter **426** have an impulse response matched the first chip-code signal, second chip-code signal, third chip-code signal, through N^{th} chip-code signal, defining the first channel, second channel, third channel through N^{th} channel, respectively, of the spread-spectrum CDMA signal. At each of the outputs of the respective first channel-matched filter **126**, second channel-matched filter **226**, third channel-matched filter **326**, through N^{th} channel-matched filter **426**, is produced an estimate of the respective first channel d_1, second channel d_2, third channel d_3, through N^{th} channel d_N.

In use, the present invention is illustrated for the first channel of the spread-spectrum CDMA signal, with the understanding that the second channel through N^{th} channel work similarly. A received spread-spectrum CDMA signal at input **41** is delayed by delay device **48** and fed to subtractor **150**. The same spread-spectrum CDMA signal has the second through N^{th} channel despread by the second matched filter **164** through the N^{th} matched filter **174**. This despreading removes the other CDMA channels form the respective despread channel. In a preferred embodiment, each of the chip-code signals used for the first channel, second channel, through the N^{th} channel, is orthogonal to the other chip-code signals. At the output of the first matched filter **154**, second matched filter **164** through N^{th} matched filter **174**, are the first despread signal, second despread signal through N^{th} despread signal, plus noise.

The respective channel is spread-spectrum processed by the processing mixers. Accordingly, at the output of the second processing mixer **65** through the N^{th} processing mixer **75** is a spread version of the second despread signal through the N^{th} despread signal, plus noise components contained therein. Each of the spread-spectrum-processed-despread signals, is then subtracted from the received spread-spectrum CDMA signal by the first subtractor **150**. This produces the first subtracted signal.

The first subtracted signal is despread by first channel-matched filter **126**. Accordingly, prior to despreading the first channel of the spread-spectrum CDMA signal, the second channel through N^{th} channel plus noise components aligned with these channels, are subtracted from the received spread-spectrum CDMA signal.

As is well known in the art, correlators and matched filters may be interchanged to accomplish the same function. FIGS. **1** and **3** show alternate embodiments using correlators or matched filters. The arrangements may be varied. For example, the plurality of despreading means may be embodied as a plurality of matched filters, while the channel despreading means may be embodied as a correlator. Alternatively, the plurality of despreading means may be a combination of matched filters and correlators. Also, the spread-spectrum-processing means may be embodied as a matched filter or SAW, or as EXCLUSIVE-OR gates or other devices for mixing a despread signal with a chip-code signal. As is well known in the art, any spread-spectrum despreader or demodulator may despread the spread-spectrum CDMA signal. The particular circuits shown in FIGS. **1**–**4** illustrate the invention by way of example.

The concepts taught in FIGS. **1**–**4** may be repeated, as shown in FIG. **5**. FIG. **5** illustrates a first plurality of interference cancelers **511**, **512**, **513**, a second plurality of interference cancelers **521**, **522**, **523**, through an N^{th} plurality of interference cancelers **531**, **532**, **533**. Each plurality of interference cancelers includes appropriate elements as already disclosed, and referring to FIGS. **1**–**4**. The input is delayed through a delay device in each interference canceler.

The received spread-spectrum CDMA signals has interference canceled initially by the first plurality of interference cancelers **511**, **512**, **513**, thereby producing a first set of estimates, i.e. a first estimate d_{11}, a second estimate d_{12}, through an N^{th} estimate d_{1N}, of the first channel, second channel through the N^{th} channel, of the spread-spectrum CDMA signal. The first set of estimates can have interference canceled by the second plurality of interference cancelers **521**, **522**, **523**. The first set of estimates $d_{11}, d_{12}, \ldots, d_{1N}$, of the first channel, second channel through N^{th} channel, are input to the second plurality of interference cancelers, interference canceler **521**, interference canceler **522** through N^{th} interference canceler **523** of the second plurality of interference cancelers. The second plurality of interference cancelers thereby produce a second set of estimates, i.e. $d_{21}, d_{22}, \ldots, d_{2N}$, of the first channel, second channel, through N^{th} channel. Similarly, the second set estimates can pass through a third plurality of interference cancelers, and ultimately through an M^{th} set of interference cancelers **531**, **532**, **533**, respectively.

The present invention also includes a method for reducing interference in a spread-spectrum CDMA receiver having N chip-code channels. Each of the N channels is identified by a distinct chip-code signal. The method comprises the steps of despreading, using a plurality of chip-code signals, the spread-spectrum CDMA signal as a plurality of despread signals, respectively. Using a timed version of the plurality of chip-code signals, the plurality of despread signals are spread-spectrum processed with a chip-code signal corresponding to a respective despread signal. Each of the N−1 spread spectrum-processed-despread signals, is subtracted from the spread-spectrum CDMA signal, with the N−1

spread-spectrum-processed-despread signals not including a spread-spectrum-processed signal of the i^{th} despread signal, thereby generating a subtracted signal. The subtracted signal is despread to generate the i^{th} channel.

The probability of error P_e for direct sequence, spread-spectrum CDMA system is:

where erfc is complementary error function, SNR is signal-to-noise ratio, and $1 \leqq \alpha \leqq 2$. The value of α depends on how a particular interference canceler system is designed.

The SNR after interference cancellation and method is given by:

where N is the number of channels, PG is the processing gain, R is the number of repetitions of the interference canceler, E_b is energy per information bit and η is noise power spectral density.

FIG. 6 illustrates theoretical performance characteristic, of the interference canceler and method for when $E_b/\eta=6$ dB. The performance characteristic is illustrated for SNR out of the interference canceler, versus PG/N. The lowest curve, for R=0, is the performance without the interference canceler. The curves, for R=1 and R=2, illustrates improved performance for using one and two iterations of the interference canceler as shown in FIG. 5. As PG/N→1, there is insufficient SNR to operate. If PG>N, then the output SNR from the interference canceler approaches E_b/η. Further, if $(N/PG)^{R+1}<<1$, then

$$SNR \rightarrow (E_b/\eta)(1-N/PG).$$

FIG. 7 illustrates the performance characteristic for when $E_b/\eta=10$ dB. FIG. 7 illustrates that three iterations of the interference canceler can yield a 4 dB improvement with PG/N=2.

FIG. 8 illustrates the performance characteristic for when $E_b/\eta=15$ dB. With this bit energy to noise ratio, two iterations of the interference canceler can yield 6 dB improvement for PG/N=2.

FIG. 9 illustrates the performance characteristic for when $E_b/\eta=20$ dB. With this bit energy to noise ratio, two iterations of the interference canceler can yield 6 dB improvement for PG/N=2. Similarly, FIGS. 10 and 11 shows that one iteration of the interference canceler can yield more than 10 db improvement for PG/N=2.

The present invention may be extended to a plurality of interference cancelers. As shown in FIG. 12, a received spread-spectrum signal, R(t), is despread and detected by CDMA/DS detector 611. Each of the channels is represented as outputs $O_{01}, O_{02}, O_{03}, \ldots, O_{0m}$. Thus, each output is a despread, spread-spectrum channel from a received spread-spectrum signal, R(t).

Each of the outputs of the CDMA/DS detector 611 is passed through a plurality of interference cancelers 612, 613, . . . , 614, which are serially connected. Each of the spread-spectrum channels passes through the interference canceling processes as discussed previously. The input to each interference canceler is attained by sampling and holding the output of the previous stage once per bit time. For channel i, the first interference canceler samples the output of the CDMA/DS detector at time $t=T+\tau_i$. This value is held constant as the input until $t=2T+\tau_i$ at which point the next bit value is sample. Thus, the input waveforms to the interference canceler are estimates, $\hat{d}_i(t-\tau_i)$, of the original data waveform $(d_i(t-\tau_i)$, and the outputs are second estimates, $\hat{\hat{d}}_i(t-\tau_i)$. The M spread-spectrum channel outputs O_{0i}, i=1, 2, . . . , M, are passed through interference canceler 612 to produce a new corresponding set of channel outputs O_{1i}, i=1, 2, . . . , M.

As shown in FIG. 13, the outputs of a particular spread-spectrum channel, which are at the output of each of the interference cancelers, may be combined. Accordingly, combiner 615 can combine the output of the first channel which is from CDMA/DS detector 611, and the output O_{11} from the first interference canceler 612, and the output O_{21} from the second interference canceler 613, through the output O_{N1} from the N^{th} interference canceler 614. Each output to be combined is of the corresponding bit. Therefore "s" bit time delays is inserted for each O_{s1}. The combined outputs are then passed through the decision device 616. This can be done for each spread spectrum channel, and therefore designate the outputs of each of the combiners 615, 617, 619 as averaged outputs O_1 for channel one, averaged output O_2 for channel two, and averaged output O_M for channel M. Each of the averaged outputs are sequentially passed through decision device 616, decision device 618, and decision device 620. Preferably, the averaged outputs have multiplying factor c_j which may vary according to a particular design. In a preferred embodiment, $c_j=\frac{1}{2}$. This allows the outputs of the various interference cancelers to be combined in a particular manner.

FIGS. 14–17 illustrate simulation performance characteristics for the arrangement of FIGS. 12 and 13. FIGS. 14–17 are for asynchronous channel (relative time delays are uniformly distributed between 0 and bit time, T), processing gain of 100, all user have equal powers, and thermal signal to noise ratio (E_bN of 30 dB). Length 8191 Gold codes are used for the PN sequences.

In FIG. 14, performance characteristic of each of the output stages of FIG. 12 is shown. Thus, S0 represents the BER performance at the output of CDMA/DS detector 611, S1 represents the BER performance at the output of interference canceler 612, S2 represents the BER performance at the output of interference canceler 613, etc. No combining of the outputs of the interference cancelers are used in determining the performance characteristic shown in FIG. 14. Instead, the performance characteristic is for repetitively using interference cancelers. As a guideline, in each of the subsequent figures the output for each characteristic of CDMA/DS detector 611 is shown in each figure.

FIG. 15 shows the performance characteristic when the output of subsequent interference cancelers are combined. This is shown for a particular channel. Thus, curve S0 is the output of the CDMA/DS detector 611. Curve S1 represents the BER performance of the average of the outputs of CDMA/DS detector 611 and interference canceler 612. Here $C_0=C_1=\frac{1}{2}$ $C_j=0$, j not equal to zero, one. Curve S2 represents the BER performance of the average output of interference canceler 613 and interference canceler 612. Curve S2 is determined using the combiner shown in FIG. 13. Here, C_1 and C_2 are set equal to ½ and all other C_j set to zero. Similarly, curve S3 is the performance of the output of a second and third interference canceler averaged together. Thus, curve S3 is the performance characteristic of the average between outputs of a second and third interference canceler. Curve S4 is the performance characteristic of the average output of a third and fourth interference canceler. Only two interference cancelers are taken at a time for determining a performance characteristic of an average output of those to particular interference cancelers.

FIG. 16 shows the regular outputs for the CDMA/DS detector 611, and a first and second interference canceler 612, 613. Additionally, the average output of the CDMA/DS detector 611 and the first interference canceler 612 is shown as S1 AVG. The BER performance of the average of the outputs of the first interference canceler 612 and the second interference canceler 613 is shown as the average output S2 AVG.

FIG. 17 shows performance characteristic correspondence for those of FIG. 16, but interms of signal to-noise ratio in decibels (dB).

It will be apparent to those skilled in the art that various modifications can be made to the spread-spectrum CDMA interference canceler and method of the instant invention without departing from the scope or spirit of the invention, and it is intended that the present invention cover modifications and variations of the spread-spectrum CDMA interference canceler and method provided they come within the scope of the appended claims and their equivalents.

We claim:

1. A multi-channel, interference canceler for code division multiple access (CDMA) telecommunication systems for use in a communication receiver wherein each channel of the multi-channel, interference canceler comprises:

a plurality of despreading means, each for despreading a specific CDMA channel to produce a channel signal;

a subtracting means having inputs associated with all but a selected despreading means for outputting an interference reference signal with respect to all despread channels except a selected channel which corresponds to said specific CDMA channel of said selected despreading means; and

means for integrating and combining the channel signal produced by said selected despreading means with said interference reference signal to produce an interference canceled signal.

2. The multi-channel, interference canceler according to claim 1 further comprising:

for each channel despreading means, a respective channel subtracting means for producing an interference reference signal for said respective channel having inputs associated with all of the other said plurality of despreading means; and

for each respective channel subtracting means, a respective integrating and combining means for combining and integrating a channel signal produced by the despreading means with the interference reference signal to produce an interference canceled signal of said respective channel.

3. The multi-channel, interference canceler according to claim 1 wherein each of said plurality of despreading means further comprises:

a chip-code generator for generating a chip-code sequence for a channel from a respective chip codeword; and

a mixer for despreading a specific CDMA channel with said chip-code sequence.

4. The multi-channel, interference canceler according to claim 1 wherein said subtracting means having an additional input in common with inputs of said plurality of processing means.

5. The multi-channel, interference canceler for code division multiple access (CDMA) telecommunication systems for use in a communication receiver wherein each channel of the multi-channel, interference canceler comprises:

a plurality of processing means, each for processing a specific CDMA channel;

a subtracting means having inputs associated with all but a selected processing means for outputting a subtracted signal; and

match means matched to a chip codeword of the specific CDMA channel associated with said selected processing means for filtering said subtracted signal to produce an interference canceled signal of the specific CDMA channel associated with said selected processing means.

6. The multi-channel, interference canceler according to claim 5 further comprising:

for each processing means, a respective channel subtracting means having inputs associated with all of the other said plurality of processing means for producing a respective subtracted signal; and

for each respective channel subtracting means, a match filtering means matched to a respective chip codeword of the respective CDMA channel associated with the processing means which is not associated with the subtracting means inputs for filtering the respective subtracted signal to produce an interference canceled signal of the respective CDMA channel.

7. The multi-channel, interference canceler according to claim 5 wherein said plurality of processing means further comprises:

a matched filter matched to a channel corresponding to a respective chip codeword;

a chip-code generator for generating a chip-code sequence for the specific channel from a respective chip codeword; and

a mixer coupled between said chip-code generator and an output of said matched filter.

8. The multi-channel, interference canceler according to claim 7, wherein said plurality of processing means further comprises:

a delaying means coupled between said chip-code generator and said mixer.

9. The multi-channel, interference canceler according to claim 5 wherein each of said plurality of processing means further comprises:

a digital signal processor (DSP) configured as a digital matched filter having an impulse response matched to a channel corresponding to a respective chip codeword.

10. The multi-channel, interference canceler according to claim 5 wherein each of said plurality of processing means further comprises:

a surface acoustic wave (SAW) device having an impulse response matched to a channel corresponding to a respective chip codeword.

11. The multi-channel, interference canceler according to claim 5 wherein said subtracting means having an additional input in common with inputs of said plurality of despreading means.

12. A method for reducing interference in a multi-channel, code division multiple access (CDMA) telecommunication system communication receiver comprising the steps of:

despreading simultaneously a plurality of specific CDMA channels;

subtracting all but a selected despread channel of the plurality of channels to produce an interference reference signal; and

integrating and combining said selected despread channel with the interference reference signal to produce an interference canceled signal for said selected channel.

13. The method for reducing interference according to claim 12 wherein said step of integrating and combining further comprises the steps of:

combining said selected channel with said interference reference signal producing a combined signal; and

integrating said combined signal to produce an interference canceled signal for said one selected channel.

14. The method for reducing interference according to claim 12 further comprising performing said subtracting and said integrating and combining steps separately with respect

to each of said specific CDMA channels such that each channel serves in turn as said selected channel.

15. The method for reducing interference according to claim **12** wherein said plurality of specific CDMA channels are despread from a multi-channel CDMA signal and said interference reference signal is produced by subtracting all but a selected despread channel of the plurality of channels from said multi-channel CDMA signal.

16. A method for reducing interference in a multi-channel, code division multiple access (CDMA) telecommunications system communication receiver comprising the steps of:

processing a multichannel CDMA signal to produce a plurality of processed signals each processed with a different CDMA channel;

subtracting all but a selected one of said plurality of processed signals to produce a subtracted signal; and

filtering said subtracted signal with respect to a chip-code associated with the specific CDMA channel corresponding to said selected one of said plurality of processed signals to produce an interference canceled signal for the specific CDMA channel.

17. A method for reducing interference according to claim **16** further comprising performing said subtracting and said filtering steps for each processed signal such that each processed signal serves in turn as said selected one of said plurality of processed signals thereby producing interference canceled signals for each CDMA channel.

18. The method for reducing interference according to claim **16** wherein all but a selected one of said plurality of processed signals are subtracted from said multi-channel CDMA signal to produce a subtracted signal.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,014,373

DATED : January 11, 2000

INVENTOR(S) : Schilling et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

At column 6, line 7, after the word "mixer", delete "63" and insert therefor --65--.

At column 11, line 7, insert therefor -- $P_e = \frac{1}{2} erfc(aSNR)^{\frac{1}{2}}$ --.

At column 11, line 12, after the words "given by:", insert therefor

$$-- SNR = \frac{(PG/N)^{R+1}}{1+(PG/N)^{R+1}\frac{1}{E_{b/\eta}}\frac{1-(N/PG)^{R+1}}{1-N/PG}} --.$$

Signed and Sealed this

Twenty-first Day of November, 2000

Attest:

Q. TODD DICKINSON

Attesting Officer

Director of Patents and Trademarks

US006259688B1

(12) **United States Patent**
Schilling et al.

(10) **Patent No.: US 6,259,688 B1**
(45) **Date of Patent: Jul. 10, 2001**

(54) **SPREAD SPECTRUM CDMA SUBTRACTIVE INTERFERENCE CANCELER SYSTEM**

(75) Inventors: **Donald L. Schilling**, Sands Point; **John Kowalski**, New York, both of NY (US)

(73) Assignee: **InterDigital Technology Corporation**, Wilmington, DE (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/276,019**

(22) Filed: **Mar. 25, 1999**

Related U.S. Application Data

(63) Continuation of application No. 08/939,146, filed on Sep. 29, 1997, now Pat. No. 6,014,373, which is a continuation of application No. 08/654,994, filed on May 29, 1996, now Pat. No. 5,719,852, which is a continuation of application No. 08/279,477, filed on Jul. 26, 1994, now Pat. No. 5,553,062, which is a continuation-in-part of application No. 08/051,017, filed on Apr. 22, 1993, now Pat. No. 5,363,403.

(51) **Int. Cl.**^{7} **H04B 7/216**
(52) **U.S. Cl.** **370/342**; 375/148
(58) **Field of Search** 370/201, 310, 370/333, 335, 331, 342, 479, 343, 464; 375/140, 141, 142, 144, 148

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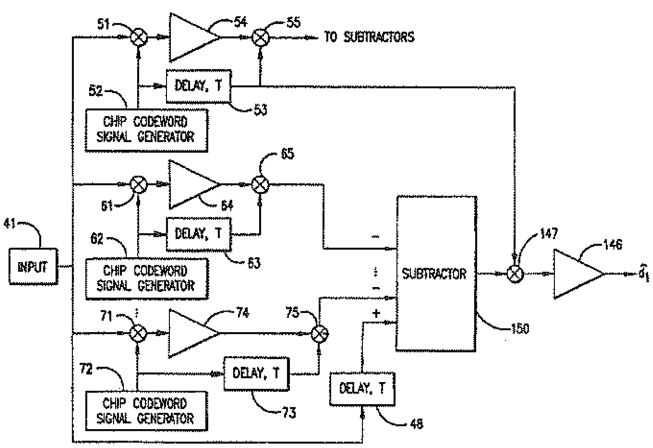
Primary Examiner—Chau Nguyen
Assistant Examiner—Alexander O. Boakye
(74) *Attorney, Agent, or Firm*—Volpe and Koenig, P.C.

(57) **ABSTRACT**

A spread spectrum code division multiple access interference canceler for reducing interference in a direct sequence CDMA receiver having N chip-code channels. The interference canceler includes a plurality of correlators or matched filters, a plurality of spread-spectrum-processing circuits, subtracting circuits, and channel correlators or channel-matched filters. Using a plurality of chip-code signals, the plurality of correlators despreads the spread-spectrum CDMA signal as a plurality of despread signals, respectively. The plurality of spread-spectrum-processing circuits uses a timed version of the plurality of chip-code signals, for spread-spectrum processing the plurality of despread signals, respectively, with a chip-code-signal corresponding to a respective despread signal. For recovering a code channel using an i^{th} chip-code-signal, the subtracting circuits subtracts from the spread-spectrum CDMA signal, each of the N−1 spread-spectrum-processing-despread signals thereby generating a subtracted signal. The N−1 spread-spectrum-processed-despread signals do not include the spread-spectrum-processed-despread signal of the i^{th} channel of the spread-spectrum CDMA signal. The channel correlator or channel-matched filter despreads the subtracted signal.

16 Claims, 14 Drawing Sheets



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Patel, Pulin and Holtzman, Jack, "Analysis of a Simple Successive Interference Cancellation Scheme in DS/CDMA System," WINLAB, Dept. Of Electrical Engineering, Rutgers, The State University of New Jersey.

* cited by examiner

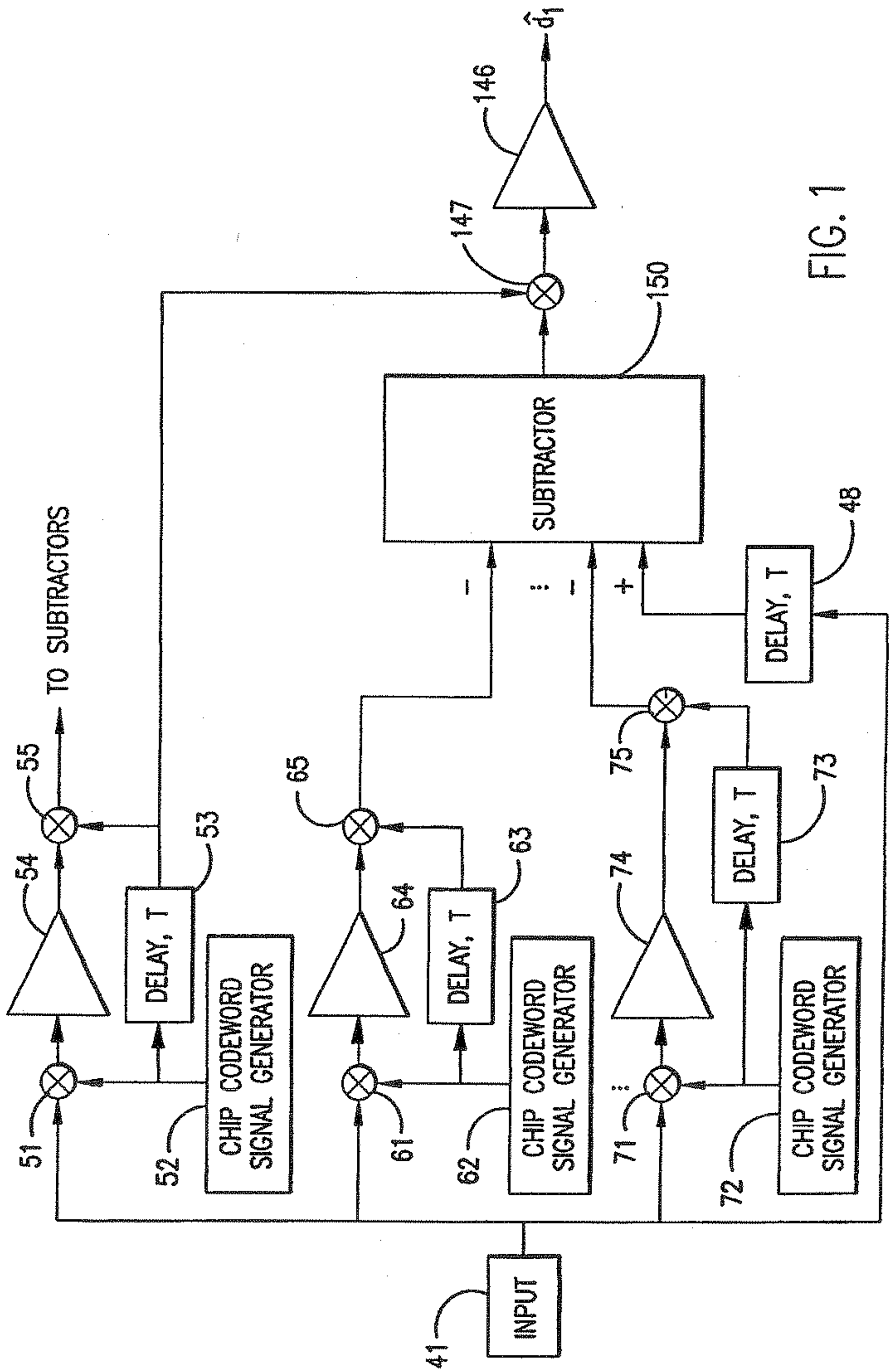

INPUT
41
CHIP CODEWORD SIGNAL GENERATOR
52
CHIP CODEWORD SIGNAL GENERATOR
62
CHIP CODEWORD SIGNAL GENERATOR
72
DELAY, T
53
DELAY, T
63
DELAY, T
73
DELAY, T
48
51
54
55
61
64
65
71
74
75
TO SUBTRACTORS
SUBTRACTOR
150
147
146
$\hat{d}_1$
-
-
+

FIG. 1

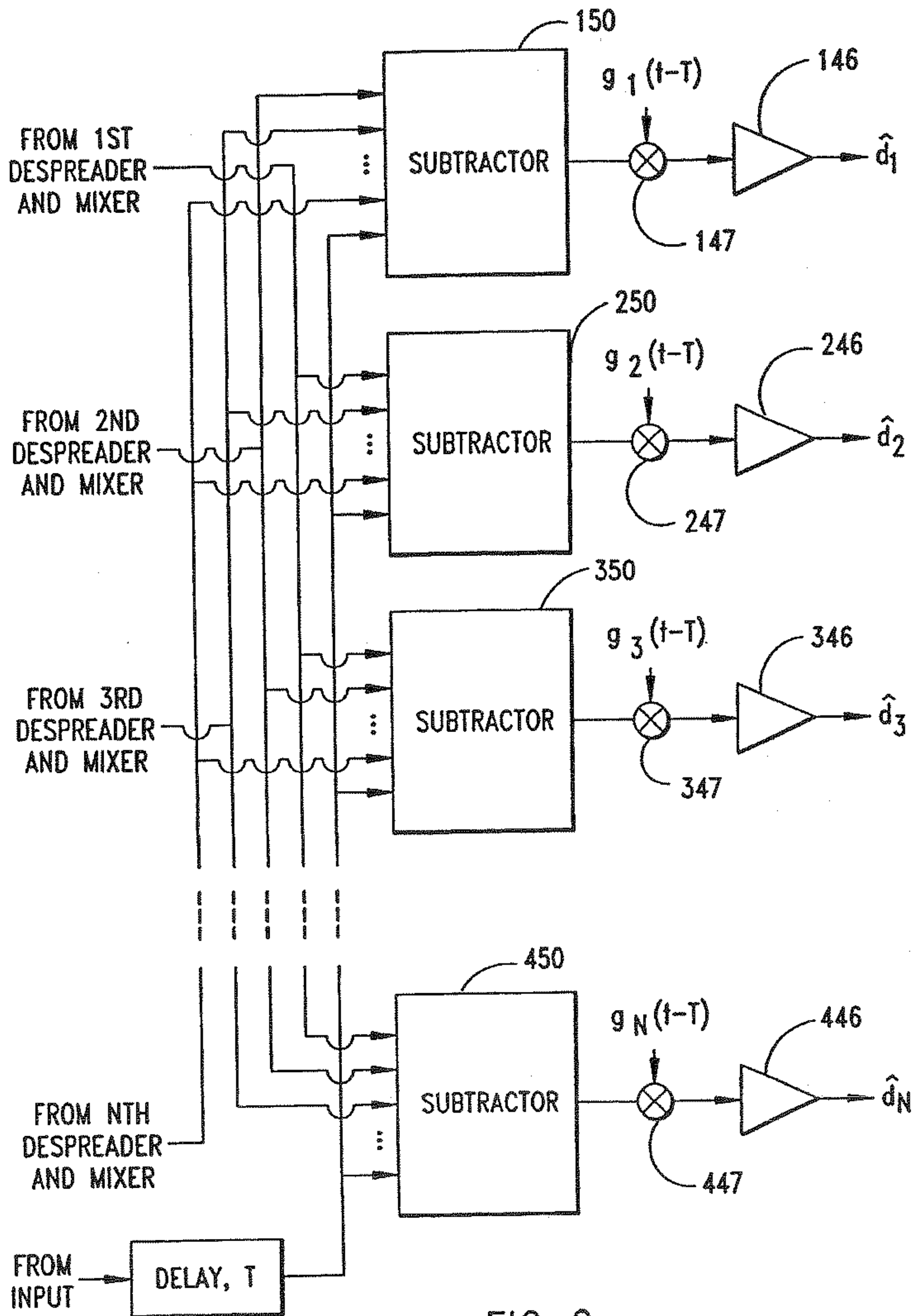
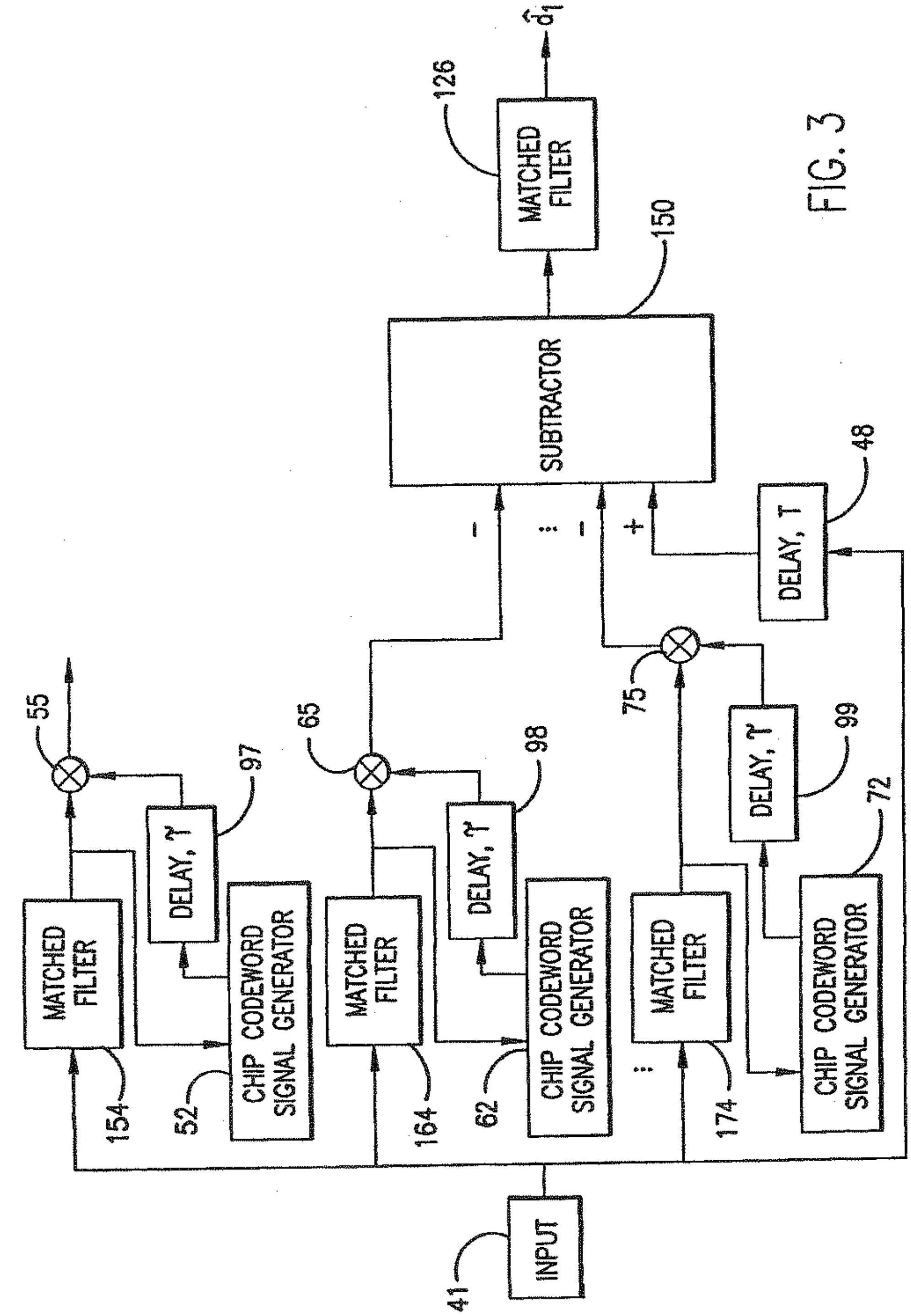

150
SUBTRACTOR
g 1 (t-T)
146
FROM 1ST DESPREADER AND MIXER
d̂1
147
250
SUBTRACTOR
g 2 (t-T)
246
FROM 2ND DESPREADER AND MIXER
d̂2
247
350
SUBTRACTOR
g 3 (t-T)
346
FROM 3RD DESPREADER AND MIXER
d̂3
347
450
SUBTRACTOR
g N (t-T)
446
FROM NTH DESPREADER AND MIXER
d̂N
447
FROM INPUT
DELAY, T

FIG. 2



INPUT
41
MATCHED FILTER
154
164
174
CHIP CODEWORD SIGNAL GENERATOR
52
62
72
DELAY, τ
97
98
99
55
65
75
DELAY, T
48
SUBTRACTOR
150
MATCHED FILTER
126
$\hat{d}_1$

FIG. 3

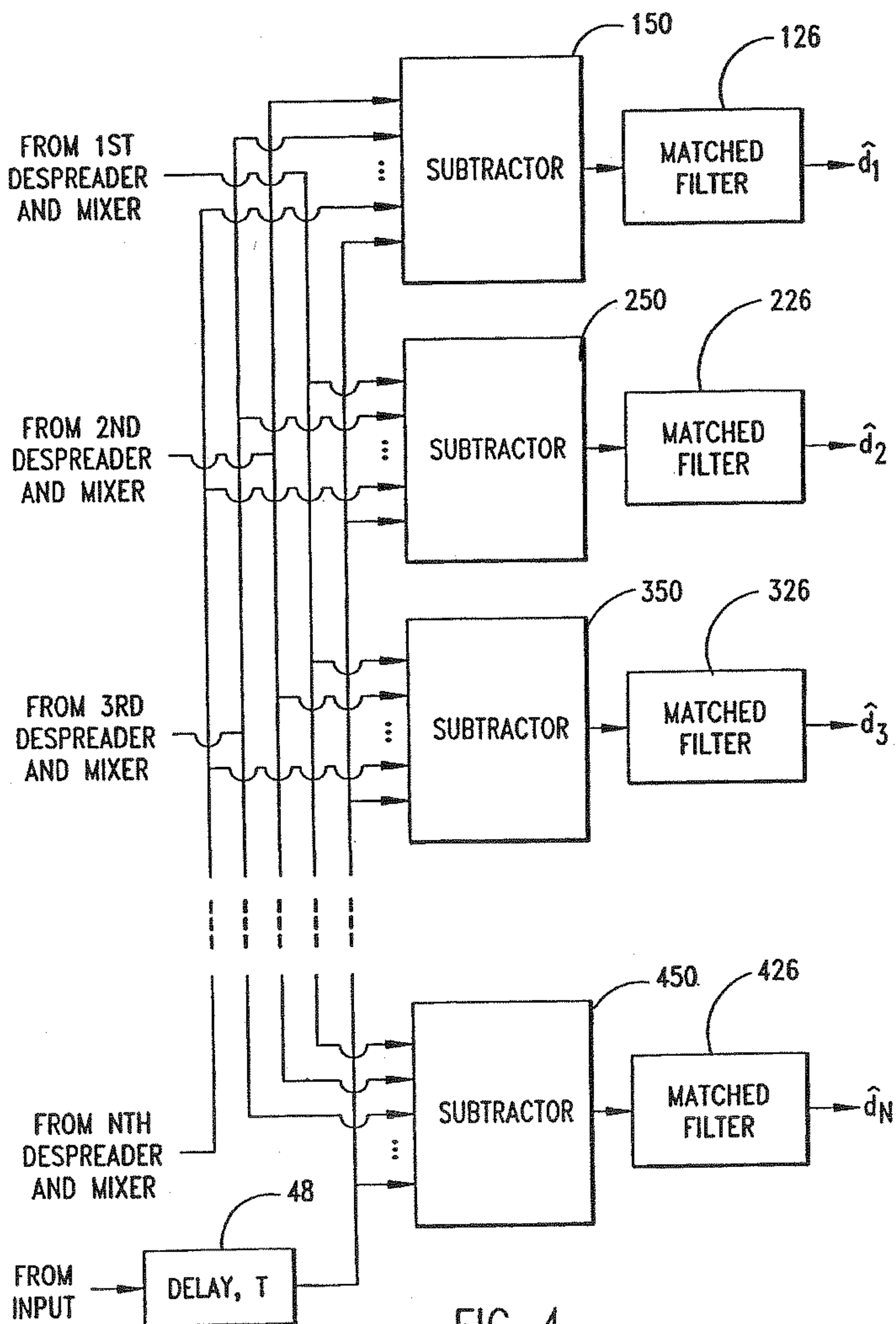

150
126
FROM 1ST DESPREADER AND MIXER
SUBTRACTOR
MATCHED FILTER
$\hat{d}_1$
250
226
FROM 2ND DESPREADER AND MIXER
SUBTRACTOR
MATCHED FILTER
$\hat{d}_2$
350
326
FROM 3RD DESPREADER AND MIXER
SUBTRACTOR
MATCHED FILTER
$\hat{d}_3$
450
426
FROM NTH DESPREADER AND MIXER
SUBTRACTOR
MATCHED FILTER
$\hat{d}_N$
48
FROM INPUT
DELAY, T

FIG. 4

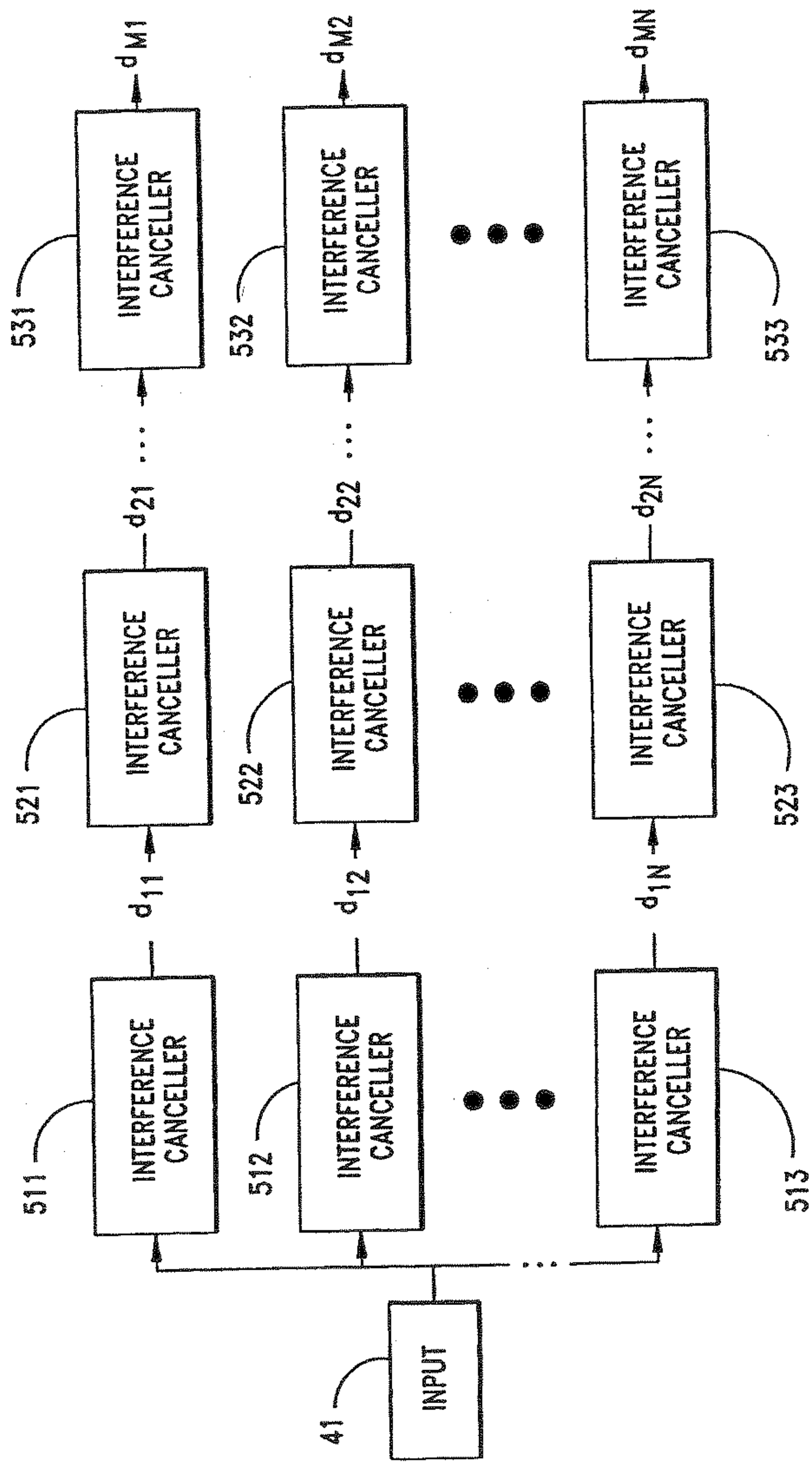

INPUT
41
INTERFERENCE CANCELLER
511
512
513
521
522
523
531
532
533
d_{11}
d_{12}
d_{1N}
d_{21}
d_{22}
d_{2N}
d_{M1}
d_{M2}
d_{MN}

FIG. 5

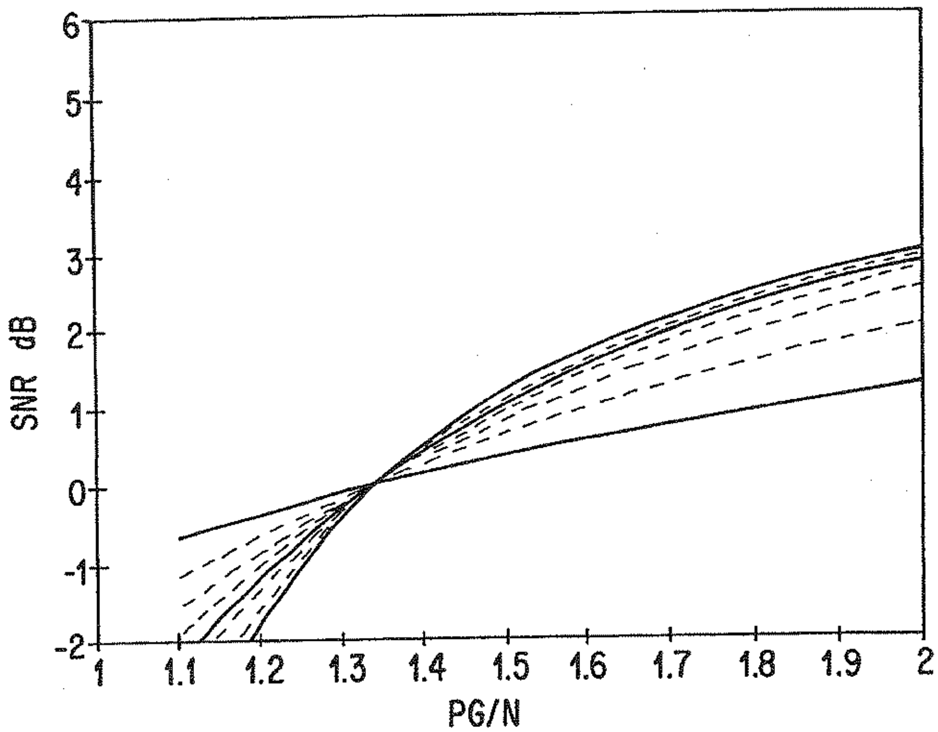

6
5
4
3
2
1
0
-1
-2
SNR dB
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

FIG.6

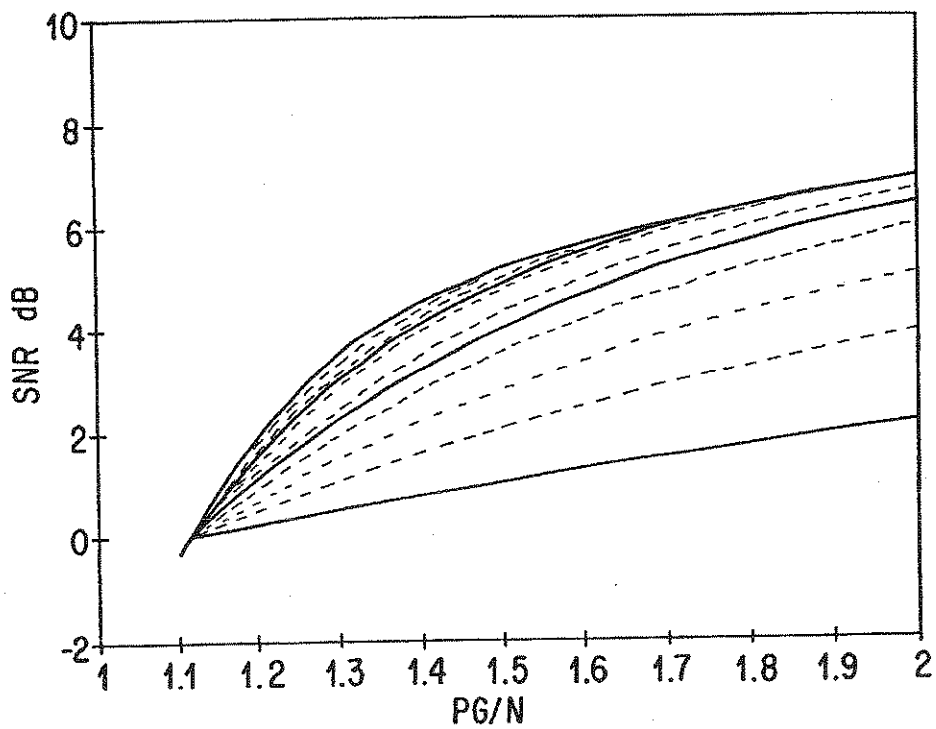
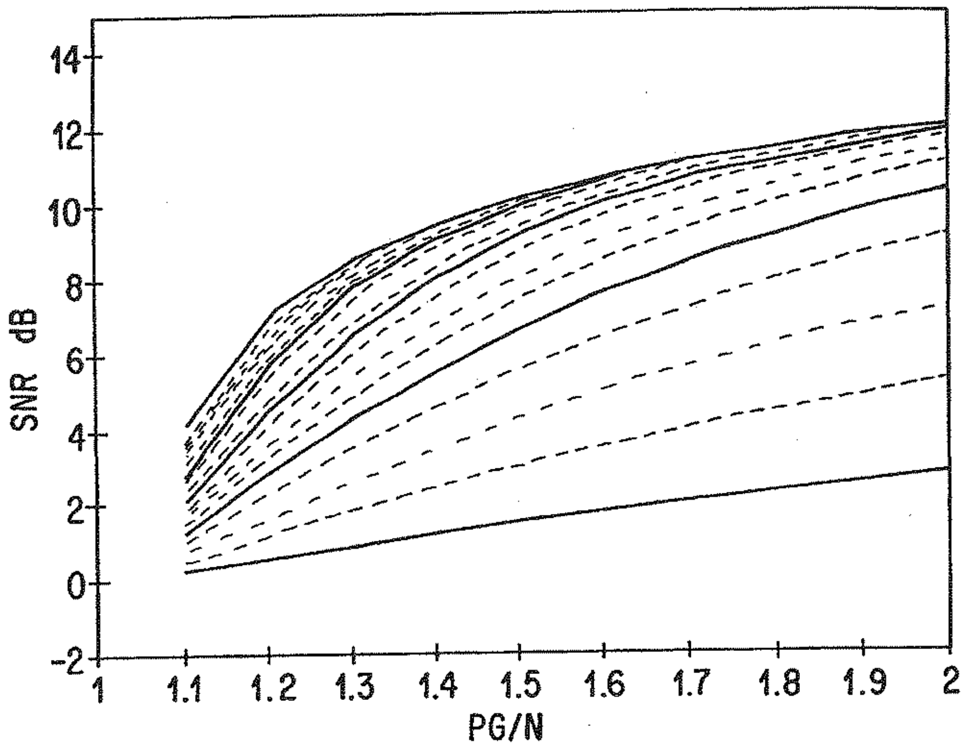
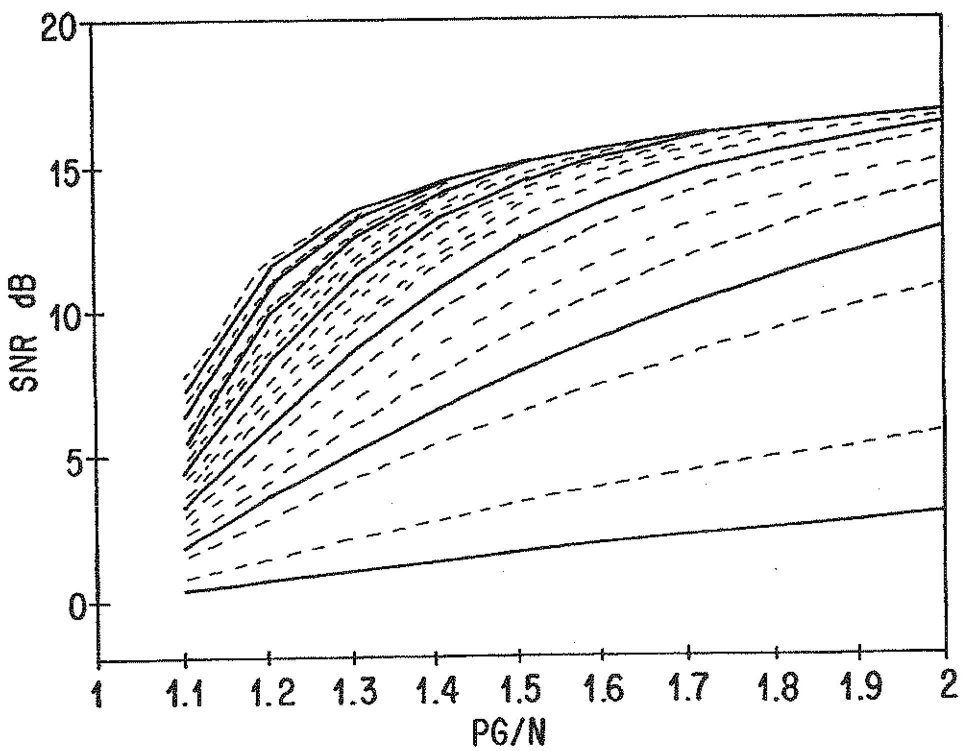

10
8
6
4
2
0
-2
SNR dB
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

FIG.7



14
12
10
8
6
4
2
0
-2
SNR dB
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

FIG. 8



20
15
10
5
0
SNR dB
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

FIG. 9

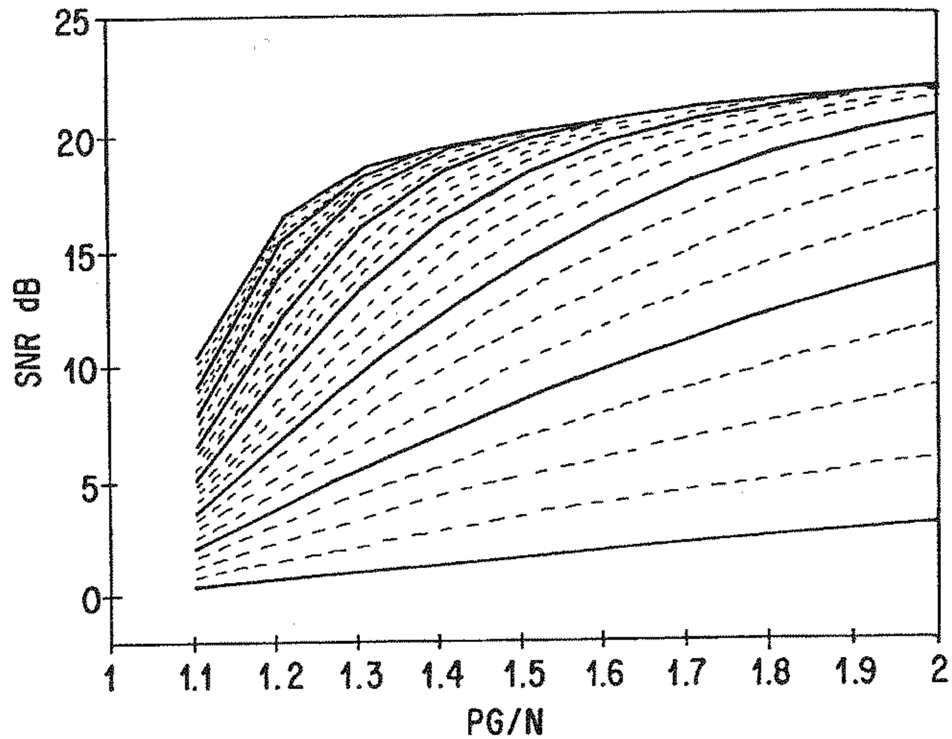

25
20
15
10
5
0
SNR dB
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

FIG.10

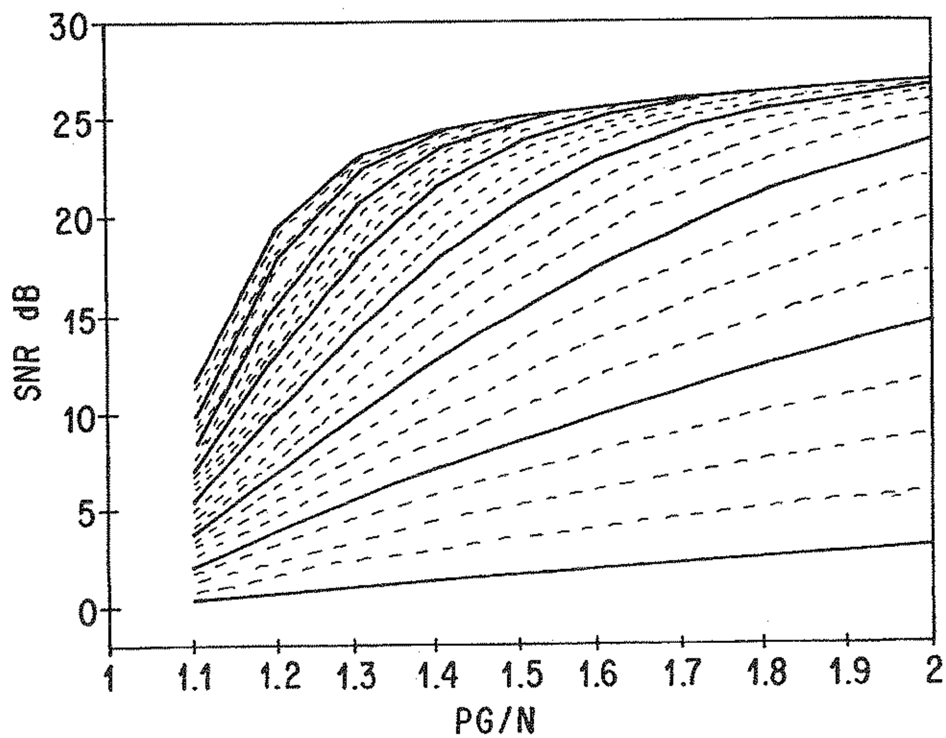

30
25
20
15
10
5
0
SNR dB
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
PG/N

FIG.11

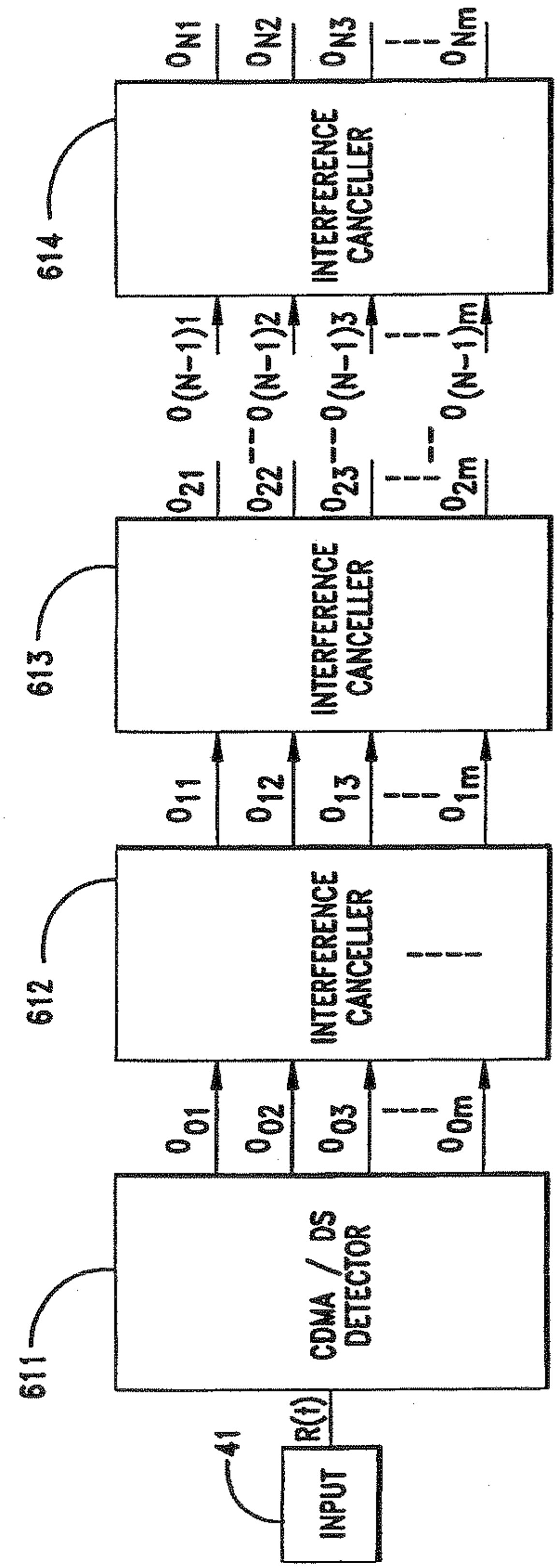
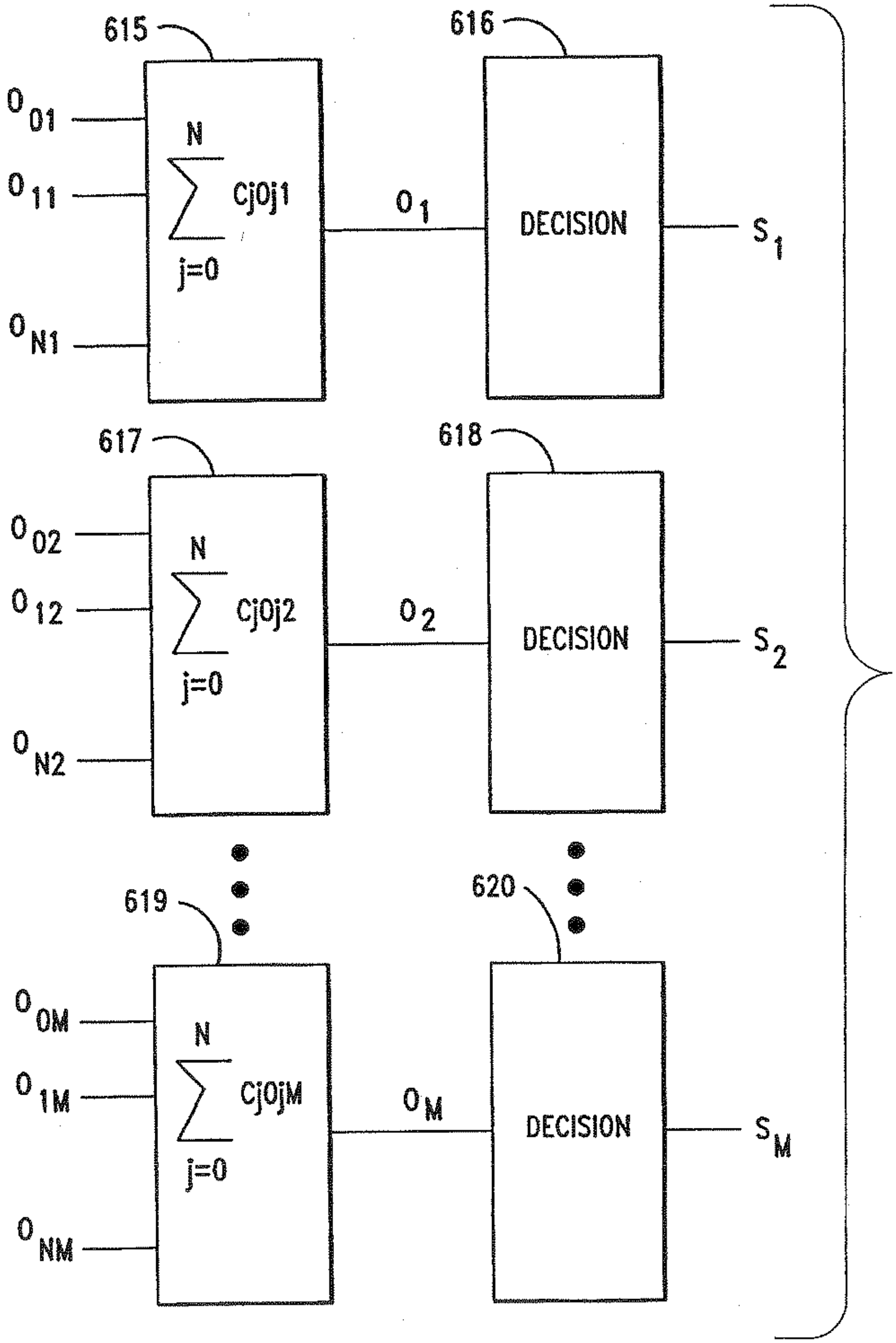

INPUT
41
R(t)
611
CDMA / DS DETECTOR
0 01
0 02
0 03
0 0m
612
INTERFERENCE CANCELLER
0 11
0 12
0 13
0 1m
613
INTERFERENCE CANCELLER
0 21
0 22
0 23
0 2m
0 (N-1)1
0 (N-1)2
0 (N-1)3
0 (N-1)m
614
INTERFERENCE CANCELLER
0 N1
0 N2
0 N3
0 Nm

FIG. 12



615
616
O_{01}
O_{11}
O_{N1}
$\sum_{j=0}^{N} CjOj1$
O_1
DECISION
S_1
617
618
O_{02}
O_{12}
O_{N2}
$\sum_{j=0}^{N} CjOj2$
O_2
DECISION
S_2
619
620
O_{0M}
O_{1M}
O_{NM}
$\sum_{j=0}^{N} CjOjM$
O_M
DECISION
S_M

FIG. 13

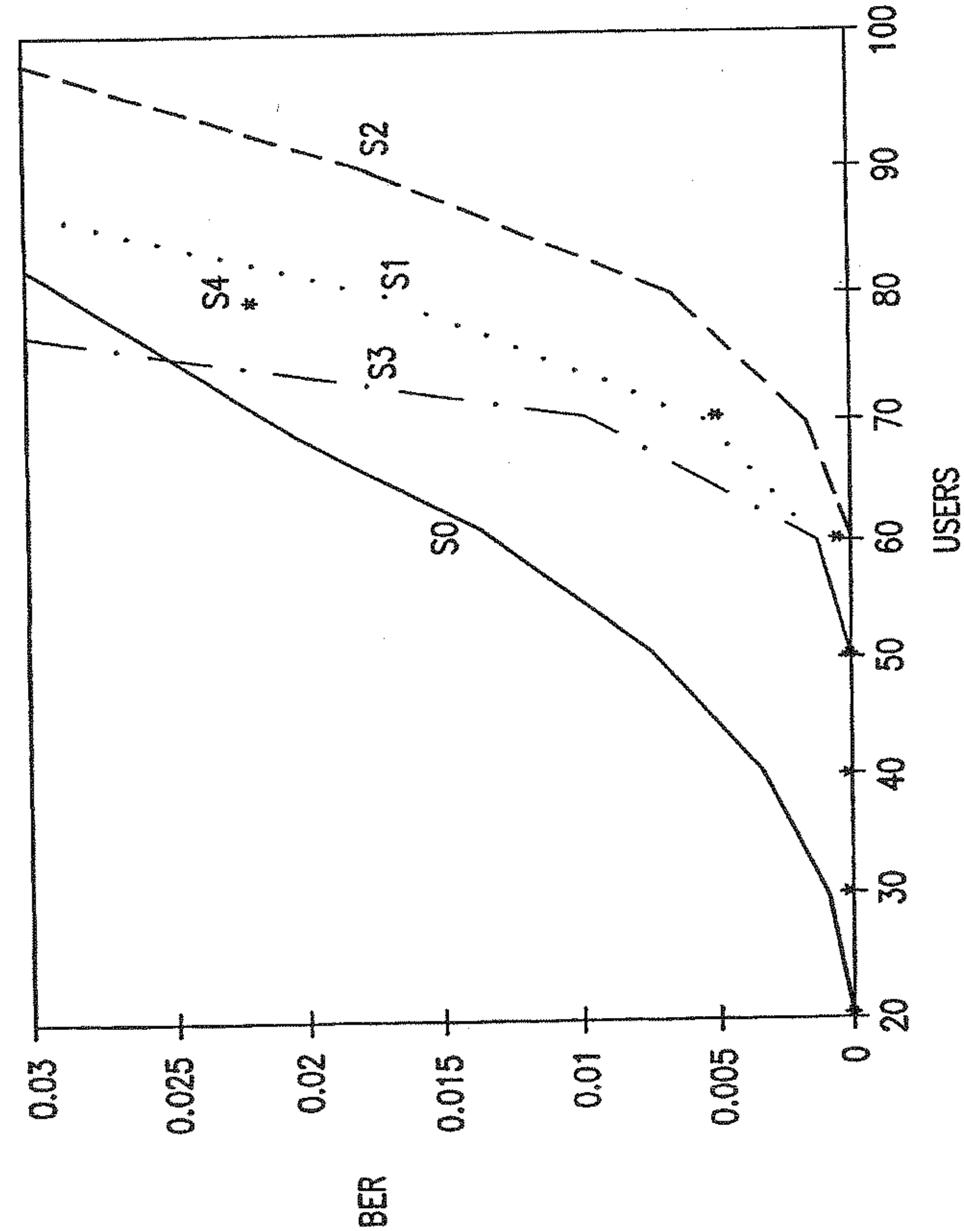

BER
0.03
0.025
0.02
0.015
0.01
0.005
0
20
30
40
50
60
70
80
90
100
USERS
S0
S1
S2
S3
S4

FIG. 14

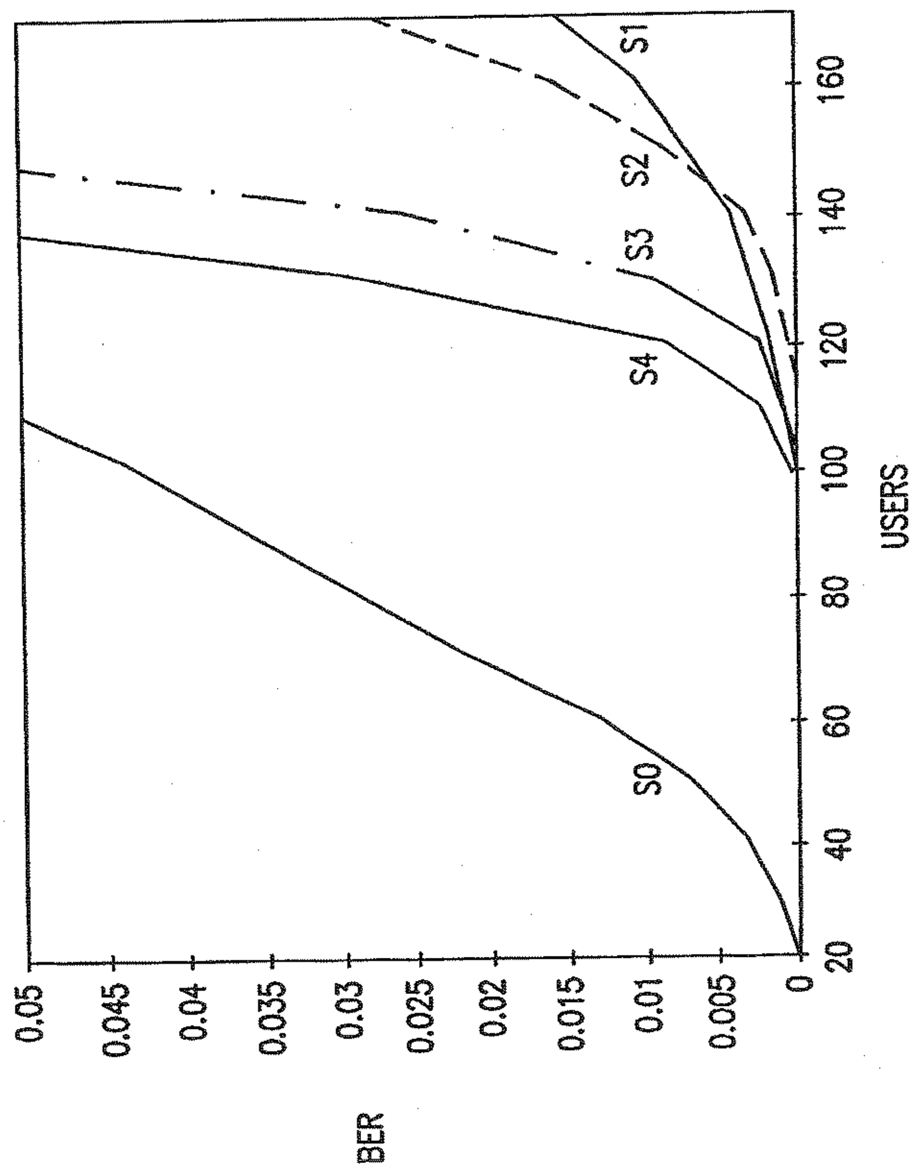

BER
USERS
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
20
40
60
80
100
120
140
160
S0
S1
S2
S3
S4

FIG. 15

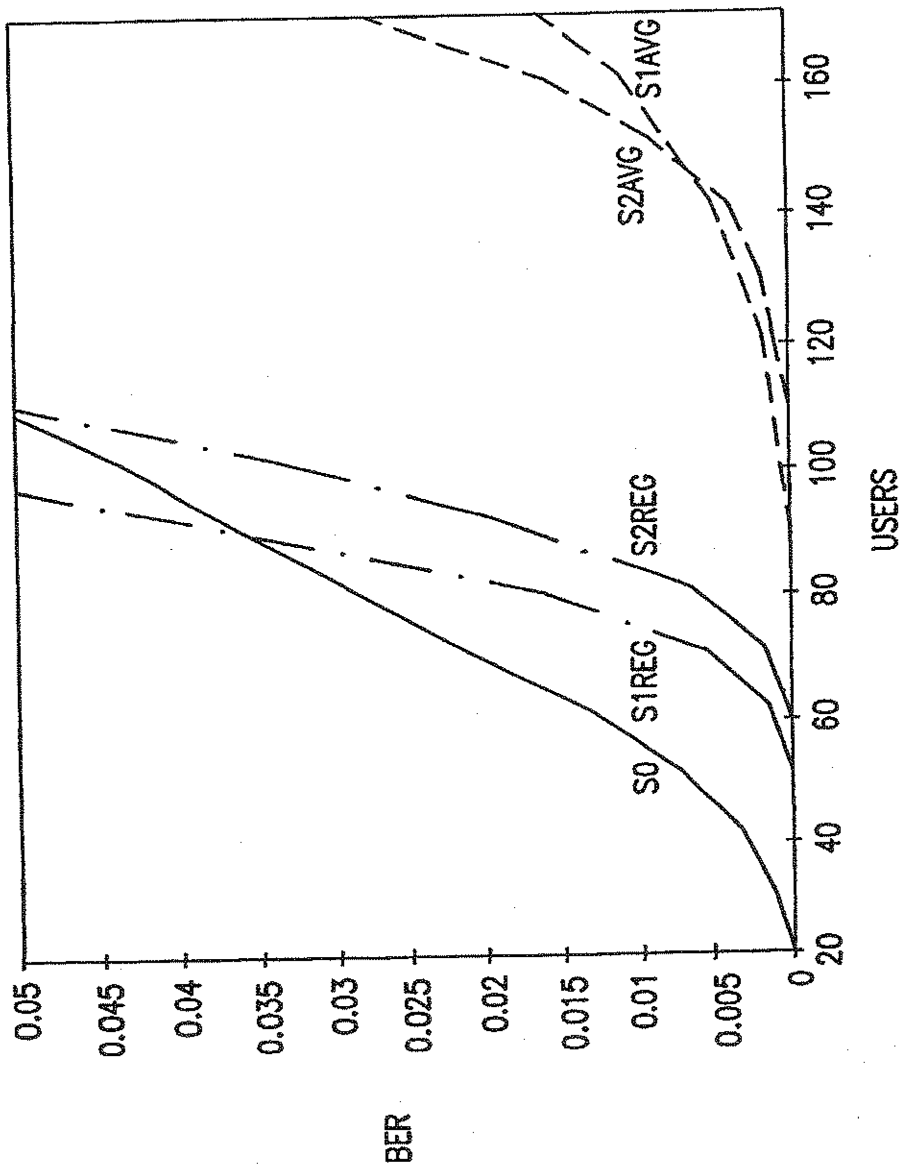

BER
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
20
40
60
80
100
120
140
160
USERS
S0
S1REG
S2REG
S2AVG
S1AVG

FIG. 16

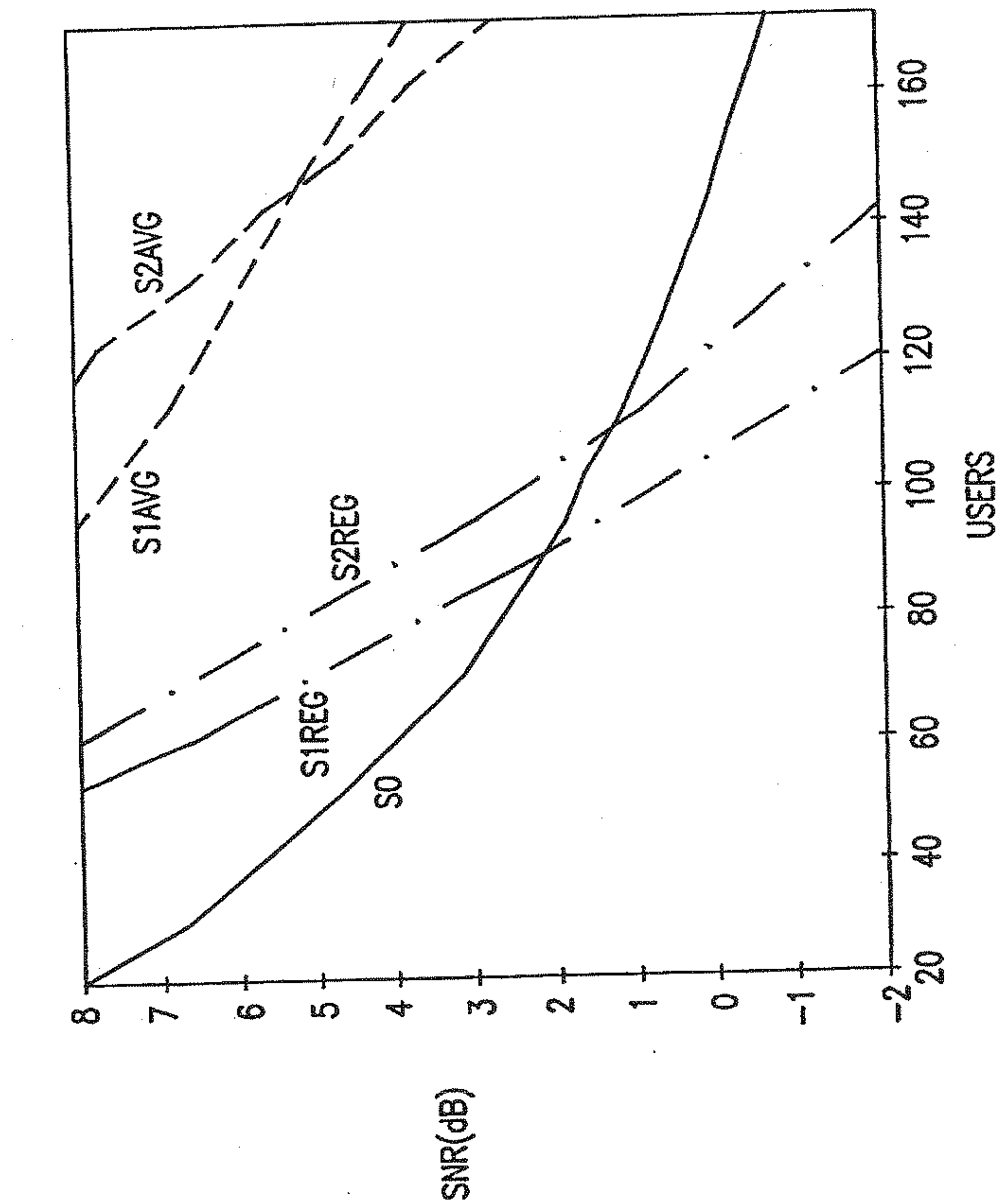

S2AVG
S1AVG
S2REG
S1REG
S0
SNR(dB)
8
7
6
5
4
3
2
1
0
−1
−2
USERS
20
40
60
80
100
120
140
160

FIG. 17

SPREAD SPECTRUM CDMA SUBTRACTIVE INTERFERENCE CANCELER SYSTEM

CROSS REFERENCES TO RELATED APPLICATIONS

This patent is a continuation application of U.S. patent application Ser. No. 08/939,146, filed Sep. 29, 1997, now U.S. Pat. No. 6,014,373, which is a continuation application of U.S. patent application Ser. No. 08/654,994, filed May 29, 1996, now U.S. Pat. No. 5,719,852, which is a continuation of U.S. patent application Ser. No. 08/279,477, filed on Jul. 26, 1994, now U.S. Pat. No. 5,553,062, which is a continuation in part of U.S. patent application Ser. No. 08/051,017, filed Apr. 22, 1993, now U.S. Pat. No. 5,363,403.

BACKGROUND OF THE INVENTION

This invention relates to spread-spectrum communications, and more particularly to an interference canceler and method for reducing interference in a direct sequence, code division multiple access receiver.

DESCRIPTION OF THE RELEVANT ART

Direct sequence, code division multiple access, spread-spectrum communications systems are capacity limited by interference caused by other simultaneous users. This is compounded if adaptive power control is not used, or is used but is not perfect.

Code division multiple access if interference limited. The more users transmitting simultaneously, the higher the bit error rate (BER). Increased capacity requires forward error correction (FEC) coding, which in turn, increases the data rate and limits capacity.

SUMMARY OF THE INVENTION

A general object of the invention is to reduce noise resulting from N−1 interfering signals in a direct sequence, spread-spectrum code division multiple access receiver.

The present invention, as embodied and broadly described herein, provides a spread-spectrum code division multiple access (CDMA) interference canceler for reducing interference in a spread-spectrum CDMA receiver having N channels. Each of the N channels is spread-spectrum processed by a distinct chip-code signal. The chip-code signal, preferably, is derived from a distinct pseudo-noise (PN) sequence, which may be generated from a distinct chip codeword. The interference canceler partially cancels N−1 interfering CDMA channels, and provides a signal-to-noise ratio (SNR) improvement of approximately N/PG, where PG is the processing gain. Processing gain is the ratio of the chip rate divided by the bit rate. By canceling or reducing interference, the SNR primarily may be due to thermal noise, and residual, interference-produced noise. Thus, the SNR may increase, lowering the BER, which reduces the demand for a FEC encoder/decoder.

The interference canceler, for a particular channel, includes a plurality of despreading means, a plurality of spread-spectrum-processing means, subtracting means, and channel-despreading means. Using a plurality of chip-code signals, the plurality of despreading means despreads the spread-spectrum CDMA signals as a plurality of despread signals, respectively. The plurality of spread-spectrum-processing means uses a timed version of the plurality of chip-code signals, for spread-spectrum processing the plurality of despread signals, respectively, with a chip-code signal corresponding to a respective despread signal. The

timed version of a chip-code signal may be generated by delaying the chip-code signal from a chip-code-signal generator. Alternatively, a matched filter may detect a particular PN sequence in the spread-spectrum CDMA signal. A chip-code-signal generator may use the detected signal from the matched filter to trigger a timed version of the chip-code signal.

For recovering a particular CDMA channel using an i^{th} chip-code signal, the subtracting means subtracts from the spread-spectrum CDMA signal, each of the N−1 spread-spectrum-processed-despread signals, thereby generating a subtracted signal. The N−1 spread-spectrum-processed-despread signals do not include the spread-spectrum-processed-despread signal of the i^{th} channel corresponding to the i^{th} chip-code signal. The channel-despreading means despreads the subtracted signal from the i^{th} chip-code signal.

The present invention also includes a method for reducing interference in a spread-spectrum CDMA receiver having N channels. The method comprises the steps of despreading, using a plurality of chip-code signals, the spread-spectrum CDMA signal as a plurality of despread signals, respectively, spread-spectrum processing, using a timed version of the plurality of chip-code signals, the plurality of despread signals, respectively, with a chip-code signal corresponding to a respective despread signal; subtracting from the spread-spectrum CDMA signal, each of the N−1 spread-spectrum-processed-despread signals, with the N−1 spread-spectrum-processed-despread signals not including a spread-spectrum-processed despread signal of the i^{th} channels, thereby generating a subtracted signal; and, despreading the subtracted signal having the i^{th} chip-code signal.

Additional objects and advantages of the invention are set forth in part in the description which follows, and in part are obvious from the description, or may be learned by practice of the invention. The objects and advantages of the invention also may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate preferred embodiments of the invention, and together with the description serve to explain the principles of the invention.

FIG. 1 is a block diagram of the spread-spectrum CDMA interference canceler using correlators;

FIG. 2 is a block diagram of the spread-spectrum CDMA interference canceler for processing multiple channels using correlators;

FIG. 3 is a block diagram of the spread-spectrum CDMA interference canceler using matched filters;

FIG. 4 is a block diagram of the spread-spectrum CDMA interference canceler for processing multiple channels using matched filters;

FIG. 5 is a block diagram of the spread-spectrum CDMA interference canceler having multiple iterations for processing multiple channels;

FIG. 6 illustrates theoretical performance characteristic for $E_b/\eta=6$ dB;

FIG. 7 illustrates theoretical performance characteristic for $E_b/\eta=10$ dB;

FIG. 8 illustrates theoretical performance characteristic for $E_b/\eta=15$ dB;

FIG. 9 illustrates theoretical performance characteristic for $E_b/\eta=20$ dB;

FIG. 10 illustrates theoretical performance characteristic for E_b/η=25 dB;

FIG. 11 illustrates theoretical performance characteristic for E_b/η=30 dB;

FIG. 12 is a block diagram of interference cancelers connected together;

FIG. 13 is a block diagram combining the outputs of the interference cancelers of FIG. 12;

FIG. 14 illustrates simulation performance characteristics for asynchronous, PG=100, Equal Powers, EbN=30 dB;

FIG. 15 illustrates simulation performance characteristics for asynchronous, PG=100, Equal Powers, EbN=30 dB;

FIG. 16 illustrates simulation performance characteristics for asynchronous, PG=100, Equal Powers, EbN=30 dB; and

FIG. 17 illustrates simulation performance characteristics for asynchronous, PG=100, Equal Powers, EbN=30 dB.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference now is made in detail to the present preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings, wherein like reference numerals indicate like elements throughout the several views.

In the exemplary arrangement shown in FIG. 1, a spread-spectrum code division multiple access (CDMA) interference canceler is provided for reducing interference in a spread-spectrum CDMA receiver having N channels. The present invention also works on a spread-spectrum code division multiplexed (CDM) system. Accordingly, without loss of generality, the term spread-spectrum CDMA signal, as used herein, includes spread-spectrum CDMA signals and spread-spectrum CDM signals. In a personal communications service, the interference canceler may be used at a base station or in a remote unit such as a handset.

FIG. 1 illustrates the interference canceler for the first channel, defined by the first chip-code signal. The interference canceler includes a plurality of despreading means, a plurality of timing means, a plurality of spread-spectrum-processing means subtracting means, and first channel-despreading means.

Using a plurality of chip-code signals, the plurality of despreading means despreads the received spread-spectrum CDMA signals as a plurality of despread signals, respectively. In FIG. 1 the plurality of despreading means is shown as first despreading means, second despreading means, through N^{th} despreading means. The first despreading means includes a first correlator, which is embodied, by way of example, as a first mixer **51**, first chip-code-signal generator **52**, and a first integrator **54**. The first integrator **54** alternatively may be a first lowpass filter or a first bandpass filter. The first mixer **51** is coupled between the input **41** and the first chip-code-signal generator **52** and the first integrator **54**.

The second despreading means includes a second correlator, which is embodied, by way of example, as second mixer **61**, second chip-code-signal generator **62** and second integrator **64**. The second integrator **64** alternatively may be a second lowpass filter or a second bandpass filter. The second mixer **61**, is coupled between the input **41**, the second chip-code-signal generator **62**, and the second integrator **64**.

The N^{th} despreading means is depicted as an N^{th} correlator shown, by way of example, as N^{th} mixer **71**, and N^{th} chip-code-signal generator **72**, and N^{th} integrator **74**. The N^{th} integrator **74** alternatively may be an N^{th} lowpass filter or an N^{th} bandpass filter. The N^{th} mixer **71** is coupled between the input **41**, the N^{th} chip-code-signal generator **72** and the N^{th} integrator **74**.

As is well known in the art, the first through N^{th} despreading means may be embodied as any device which can despread a channel in a spread-spectrum signal.

The plurality of timing means may be embodied as a plurality of delay devices **53**, **63**, **73**. A first delay device **53** has a delay time T, which is approximately the same as the integration time T_b of first integrator **54**, or time constant of the first lowpass filter or first bandpass filter. A second delay device **63** has a time delay T, which is approximately the same as the integration time T_b of second integrator **64**, or time constant of the second lowpass filter or second bandpass filter. Similarly, the N^{th} delay device **73** has a time delay T, which is approximately the same as the integration time T_b of N^{th} integrator **74**, or time constant of the N^{th} lowpass filter or N^{th} bandpass filter. Typically, the integration times of the first integrator **54**, second integrator **64** through N^{th} integrator **74** are the same. If lowpass filters are used, then typically the time constants of the first lowpass filter, second lowpass filter through N^{th} lowpass filter are the same. If bandpass filters are used, then the time constants of the first bandpass filter, second bandpass filter through N^{th} bandpass filter are the same.

The plurality of spread-spectrum-processing means regenerates each of the plurality of despread signals as a plurality of spread-spectrum signals. The plurality of spread-spectrum-processing means uses a timed version, i.e. delayed version, of the plurality of chip-code signals, for spread-spectrum processing the plurality of despread signals, respectively, with a chip-code signal corresponding to a respective despread signal. The plurality of spread-spectrum-processing means is shown, by way of example, as a first processing mixer **55**, a second processing mixer **65**, through an N^{th} processing mixer **75**. The first processing mixer **55** is coupled to the first integrator **54**, and through a first delay device **53** to the first chip-code-signal generator **52**. The second processing mixer **65** is coupled to the second integrator **64**, and through the second delay device **63** to the second chip-code-signal generator **62**. The N^{th} processing mixer **75** is coupled to the N^{th} integrator **74** through the delay device **73** to the N^{th} chip-code-signal generator **72**.

For reducing interference to a channel using an i^{th} chip-code signal of the spread-spectrum CDMA signal, the subtracting means subtracts, from the spread-spectrum CDMA signal, each of the N−1 spread-spectrum-processed-despread signals not corresponding to the i^{th} channel. The subtracting means thereby generates a subtracted signal. The subtracting means is shown as a first subtractor **150**. The first subtractor **150** is shown coupled to the output of the second processing mixer **65**, through the N^{th} processing mixer **75**. Additionally, the first subtractor **150** is coupled through a main delay device **48** to the input **41**.

The i^{th} channel-despreading means despreads the subtracted signal with the i^{th} chip-code signal as the i^{th} channel. The first channel-despreading means is shown as a first channel mixer **147**. The first channel mixer **147** is coupled to the first delay device **53**, and to the first subtractor **150**. The first channel integrator **146** is coupled to the first channel mixer **147**.

The first chip-code-signal generator **52**, the second chip-code-signal generator **62**, through the N^{th} chip-code-signal generator **72** generate a first chip-code signal, a second chip-code signal, through a N^{th} chip-code signal, respectively. The term "chip-code signal" is used herein to mean

the spreading signal of a spread-spectrum signal, as is well known in the art. Typically the chip-code signal is generated from a pseudorandom (PN) sequence. The first chip-code signal, the second chip code signal, through the N^{th} chip-code signal might be generated from a first PN sequence, a second PN sequence, through a N^{th} PN sequence, respectively. The first PN sequence is defined by or generated from a first chip codeword, the second PN sequence is defined by or generated from a second chip codeword, through the N^{th} PN sequence is defined by or generated from a N^{th} chip-codeword. Each of the first chip codeword, second chip codeword through N^{th} chip codeword is distinct, i.e. different from one another. In general, a chip codeword can be the actual sequence of a PN sequence, or used to define settings for generating the PN sequence. The settings might be the delay taps of shift registers, for example.

A first channel of a received spread-spectrum CDMA signal at input **41** is despread by first mixer **51** as a first despread signal, using the first chip-code signal generated by first chip-code-signal generator **52**. The first despread signal from the first mixer **51** is filtered through first integrator **54**. First integrator **54** integrates for a time T_b, the time duration of a symbol such a bit. At the same time, the first chip-code signal is delayed by time T by delay device **53**. The delay time T is approximately equal to the integration time T_b plus system or component delays. Systems or component delays are usually small, compared to integration time T_b.

The delayed version of the first chip-code signal is processed with the first despread signal from the output of the first integrator **54** using the first despreading mixer **55**. The output of the first spreading mixer **55** is fed to subtractors other than first subtractor **150** for processing the second through N^{th} channels of the spread-spectrum CDMA signal.

For reducing interference to the first channel of the spread-spectrum CDMA signal, the received spread-spectrum CDMA signal is processed by the second through N^{th} despreaders as follows. The second channel of the spread-spectrum CDMA signal is despread by the second despreading means. At the second mixer **61**, a second chip-code signal, generated by the second chip-code-signal generator **62**, despreads the second channel of the spread-spectrum CDMA signal. The despread second channel is filtered through second integrator **64**. The output of the second integrator **64** is the second despread signal. The second despread signal is spread-spectrum processed by second processing mixer **65** by a delayed version of the second chip-code signal. The second chip-code signal is delayed through delay device **63**. The delay device **63** delays the second chip-code signal by time T. The second channel mixer **65** spread-spectrum processes a timed version, i.e. delayed version, of the second chip-code signal with the filtered version of the second spread-spectrum channel from second integrator **64**. The term "spread-spectrum process" as used herein includes any method for generating a spread-spectrum signal by mixing or modulating a signal with a chip-code signal. Spread-spectrum processing may be done by product devices, EXCLUSIVE-OR gates, matched filters, or any other device or circuit as is well known in the art.

Similarly, the N^{th} channel of the spread-spectrum CDMA signal is despread by the N^{th} despreading means. Accordingly, the received spread-spectrum CDMA signal has the N^{th} channel despread by N^{th} mixer **71**, by mixing the spread-spectrum CDMA signal with the N^{th} chip-code signal from N^{th} chip-code-signal generator **72**. The output of the N^{th} mixer **71** is filtered by N^{th} integrator **74**. The output of the N^{th} integrator **74**, which is the N^{th} despread signal, is a despread and filtered version of the N^{th} channel of the spread-spectrum CDMA signal. The N^{th} despread signal is spread-spectrum processed by a delayed version of the N^{th} chip-code signal. The N^{th} chip-code signal is delayed through N^{th} delay device **73**. The N^{th} processing mixer **75** spread-spectrum processes the timed version, i.e. a delayed version, of the N^{th} chip-code signal with the N^{th} despread signal.

At the first subtractor **150**, each of the outputs of the second processing mixer **65** through the N^{th} processing mixer **75** is subtracted from a timed version, i.e. a delayed version, of the spread-spectrum CDMA signal from input **41**. The delay of the spread-spectrum CDMA signal is timed through the first main delay device **48**. Typically, the delay of the first main delay device **48** is time T, which is approximately equal to the integration time of the first integrator **54** through N^{th} integrator **74**.

At the output of the first subtractor **150**, is generated a first subtracted signal. The first subtracted signal, for the first channel of the spread-spectrum CDMA signal, is defined herein to be the outputs from the second processing mixer **65** through N^{th} processing mixer **75**, subtracted from the delayed version of the spread-spectrum CDMA signal. The second subtracted signal through N^{th} subtracted signal are similarly defined.

The delayed version of the first chip-code signal from the output of first delay device **53** is used to despread the output of the first subtractor **150**. Accordingly, the first subtracted signal is despread by the first chip-code signal by first channel mixer **147**. The output of the first channel mixer **147** is filtered by first channel integrator **147**. This produces an output estimate d_1 of the first channel of the spread-spectrum CDMA signal.

As illustratively shown in FIG. **2**, a plurality of subtractors **150, 250, 350, 450** can be coupled appropriately to the input **41** and to a first spreading mixer **55**, second spreading mixer **65**, third spreading mixer, through an N^{th} spreading mixer **75** of FIG. **1**. The plurality of subtractors **150, 250, 350, 450** also are coupled to the main delay device **48** from the input **41**. This arrangement can generate a first subtracted signal from the first subtractor **150**, a second subtracted signal from the second subtractor **250**, a third subtracted signal from the third subtractor **350**, through an N^{th} subtracted signal from an N^{th} subtractor **450**.

The outputs of the first subtractor **150**, second subtractor **250**, third subtractor **350**, through the N^{th} subtractor **450** are each coupled to a respective first channel mixer **147**, second channel mixer **247**, third channel mixer **347**, through N^{th} channel mixer **447**. Each of the channel mixers is coupled to a delayed version of the first chip-code signal, $g_1(t-T)$, second chip-code signal, $g_2(t-T)$, third chip-code signal, $g_3(t-T)$, through N^{th} chip-code signal, $g_N(t-T)$. The outputs of each of the respective first channel mixer **147**, second channel mixer **247**, third channel mixer **347**, through N^{th} channel mixer **447** are coupled to a first channel integrator **146**, second channel integrator **246**, third channel integrator **346** through N^{th} channel integrator **446**, respectively. At the output of each of the channel integrators is produced an estimate of the respective first channel d_1, second channel d_2, third channel d_3, through N^{th} channel d_N.

Referring to FIG. **1**, use of the present invention is illustrated for the first channel of the spread-spectrum CDMA signal, with the understanding that the second through N^{th} CDMA channels work similarly. A received spread-spectrum CDMA signal at input **41** is delayed by delay device **48** and fed to the first subtractor **150**. The spread-spectrum CDMA signal has the second channel

through N^{th} channel despread by second mixer **61** using the second chip-code signal, through the N^{th} mixer **71** using the N^{th} chip-code signal. The respective second chip-code signal through the N^{th} chip-code signal are generated by the second chip-code-signal generator **62** through the N^{th} chip-code-signal generator **72**. The second channel through N^{th} channel are despread and filtered through the second integrator **64** through the N^{th} integrator **74**, respectively. The despreading removes, partially or totally, the non-despread channels at the outputs of each of the second integrator **64** through N^{th} integrator **74**.

In a preferred embodiment, each of the chip-code signal used for the first chip-code-signal generator **52**, second chip-code-signal generator **62** through the N^{th} chip-code-signal generator **72**, are orthogonal to each other. Use of chip-code signals having orthogonally however, is not required for operation of the present invention. When using orthogonal chip-code signals, the despread signals have the respective channel plus noise at the output of each of the integrators. With orthogonal chip-code signals, theoretically the mixers remove channels orthogonal to the despread channel. The respective channel is spread-spectrum processed by the respective processing mixer.

At the output of the second processing mixer **65** through the N^{th} processing mixer **75** is a respread version of the second channel through the N^{th} channel, plus noise components contained therein. Each of the second channel through N^{th} channel is then subtracted from the received spread-spectrum CDMA signal by the first subtractor **150**. The first subtractor **150** produces the first subtracted signal. The first subtracted signal is despread by a delayed version of the first chip-code signal by first channel mixer **147**, and filtered by first channel filter **146**. Accordingly, prior to despreading the first channel of the spread-spectrum CDMA signal, the second through N^{th} channels plus noise components aligned with these channels are subtracted from the received spread-spectrum CDMA signal. As illustratively shown in FIG. **3**, an alternative embodiment of the spread-spectrum CDMA interference canceler includes a plurality of first despreading means, a plurality of spread-spectrum-processing means, subtracting means, and second despreading means. In FIG. **3**, the plurality of despreading means is shown as first despreading means, second despreading means through N^{th} despreading means. The first despreading means is embodied as a first matched filter **154**. The first matched filter **154** has an impulse response matched to the first chip-code signal, which is used to spread-spectrum process and define the first channel of the spread-spectrum CDMA signal. The first matched filter **154** is coupled to the input **41**.

The second despreading means is shown as second matched filter **164**. The second matched filter **164** has an impulse response matched to the second chip-code signal, which is used to spread-spectrum process and define the second channel of the spread-spectrum CDMA signal. The second matched filter **164** is coupled to the input **41**.

The N^{th} despreading means is shown an N^{th} matched filter **174**. The N^{th} matched filter has an impulse response matched to the N^{th} chip-code signal, which is used to spread-spectrum process and define the N^{th} channel of the spread-spectrum CDMA signal. The N^{th} matched filter is coupled to the input **41**.

The term matched filter, as used herein, includes any type of matched filter that can be matched to a chip-code signal. The matched filter may be a digital matched filter or analog matched filter. A surface acoustic wave (SAW) device may be used at a radio frequency (RF) or intermediate frequency (IF). Digital signal processors are application specific integrated circuits (ASIC) having matched filters may be used at RF, IF or baseband frequency.

In FIG. **3**, the plurality of spread-spectrum-processing means is shown as the first processing mixer **55**, the second processing mixer **65**, through the N^{th} processing mixer **75**. The first processing mixer **55** may be coupled through a first adjustment device **97** to the first chip-code-signal generator **52**. The second processing mixer **65** may be coupled through the second adjustment device **98** to the second chip-code-signal generator **62**. The N^{th} processing mixer **75** may be coupled through the N^{th} adjustment device **73** to the N^{th} chip-code-signal generator **72**. The first adjustment device **97**, second adjustment device **98** through N^{th} adjustment device **99** are optional, and are used as an adjustment for aligning the first chip-code signal, second chip-code signal through N^{th} chip-code signal with the first despread signal, second despread signal through N^{th} despread signal, outputted from the first matched filter **154**, second matched filter **164** through N^{th} matched filter **174**, respectively.

The subtracting means is shown as the first subtractor **150**. The first subtractor **150** is coupled to the output of the second processing mixer **65**, through the N^{th} processing mixer **75**. Additionally, the first subtractor **150** is coupled through the main delay device **48** to the input **41**.

The first channel-despreading means is shown as a first channel-matched filter **126**. The first channel-matched filter **126** is coupled to the first subtractor **150**. The first channel-matched filter **126** has an impulse response matched to the first chip-code signal.

A first channel of a received spread-spectrum CDMA signal, at input **41**, is despread by first matched filter **154**. The first matched filter **154** has an impulse response matched to the first chip-code signal. The first chip-code signal defines the first channel of the spread-spectrum CDMA signal, and is used by the first chip-code-signal generator **52**. The first chip-code signal may be delayed by adjustment time τ by adjustment device **97**. The output of the first matched filter **154** is spread-spectrum processed by the first processing mixer **55** with the first chip-code signal. The output of the first processing mixer **55** is fed to subtractors other than the first subtractor **150** for processing the second channel through N^{th} channel of the spread-spectrum CSMA signals.

For reducing interference to the first spread-spectrum channel, the received spread-spectrum CDMA signal is processed by the second despreading means through N^{th} despreading means as follows. The second matched filter **164** has an impulse response matched to the second chip-code signal. The second chip-code signal defines the second channel of the spread-spectrum CDMA signal, and is used by the second chip-code-signal generator **62**. The second matched filter **164** despreads the second channel of the spread-spectrum CDMA signal. The output of the second matched filter **164** is the second despread signal. The second despread signal triggers second chip-code-signal generator **62**. The second despread signal also is spread-spectrum processed by second processing mixer **65** by a timed version of the second chip-code signal. The timing of the second chip-code signal triggers the second despread signal from the second matched filter **164**.

Similarly, the N^{th} channel of the spread-spectrum CDMA signal is despread by the N^{th} despreading means. Accordingly, the received spread-spectrum CDMA signal has the N^{th} channel despread by N^{th} matched filter **174**. The output of the N^{th} matched filter **174** is then N^{th} despread

signal, i.e. a despread and filtered version of the N^{th} channel of the spread-spectrum CDMA signal. The N^{th} despread signal is spread-spectrum processed by a timed version of the N^{th} chip-code signal. The timing of the N^{th} chip-code signal is triggered by the N^{th} despread signal from the N^{th} matched filter **174**. The N^{th} processing mixer **75** spread-spectrum processes the timed version of the N^{th} chip-code signal with the N^{th} despread signal.

At the first subtractor **150**, each of the outputs of the second processing mixer **65** through the N^{th} processing mixer **75** are subtracted from a delayed version of the spread-spectrum CDMA signal from input **41**. The delay of the spread-spectrum CDMA signal is timed through delay device **48**. The time of delay device **48** is set to align the second through N^{th} spread-spectrum-processed-despread signals for subtraction from the spread-spectrum CDMA signal. This generates at the output of the first subtractor **150**, a first subtracted signal. The subtracted signal is despread by the first channel-matched filter **126**. This produces an output estimate d_1 of the first channel of the spread-spectrum CDMA signal.

As illustrated in FIG. **4**, a plurality of subtractors **150**, **250**, **350**, **450** can be coupled appropriately to the output from a first processing mixer, second processing mixer, third processing mixer, through a N^{th} processing mixer, and to a main delay device from the input. A first subtracted signal is outputted from the first subtractor **150**, a second subtracted signal is outputted from the second subtractor **250**, a third subtracted signal is outputted from the third subtractor **350**, through an N^{th} subtractor signal is outputted from an N^{th} subtractor **450**.

The output of the first subtractor **150**, second subtractor **250**, third subtractor **350**, through the N^{th} subtractor **450** are each coupled to a respective first channel-matched filter **126**, second channel-matched filter **226**, third channel-matched filter **326**, through N^{th} channel-matched filter **426**. The first channel-matched filter **126**, second channel-matched filter **226**, third channel-matched filter **326** through N^{th} channel-matched filter **426** have an impulse response matched the first chip-code signal, second chip-code signal, third chip-code signal, through N^{th} chip-code signal, defining the first channel, second channel, third channel through N^{th} channel, respectively, of the spread-spectrum CDMA signal. At each of the outputs of the respective first channel-matched filter **126**, second channel-matched filter **226**, third channel-matched filter **326**, through N^{th} channel-matched filter **426**, is produced an estimate of the respective first channel d_1, second channel d_2, third channel d_3, through N^{th} channel d_n.

In use, the present invention is illustrated for the first channel of the spread-spectrum CDMA signal, with the understanding that the second channel through N^{th} channel work similarly. A received spread-spectrum CDMA signal at input **41** is delayed by delay device **48** and fed to subtractor **150**. The same spread-spectrum CDMA signal has the second through N^{th} channel despread by the second matched filter **164** through the N^{th} matched filter **174**. This despreading removes the other CDMA channels from the respective despread channel. In a preferred embodiment, each of the chip-code signals used for the first channel, second channel, through the N^{th} channel, is orthogonal to the other chip-code signals. At the output of the first matched filter **154**, second matched filter **164** through N^{th} matched filter **174**, are the first despread signal, second despread signal through N^{th} despread signal, plus noise.

The respective channel is spread-spectrum processed by the processing mixers. Accordingly, at the output of the second processing mixer **65** through the N^{th} processing mixer **75** is a spread version of the second despread signal through the N^{th} despread signal, plus noise components contained therein. Each of the spread-spectrum-processed-despread signals, is then subtracted from the received spread-spectrum CDMA signal by the first subtractor **150**. This produces the first subtracted signal.

The first subtracted signal is despread by first channel-matched filter **126**. Accordingly, prior to despreading the first channel of the spread-spectrum CDMA signal, the second channel through N^{th} channel plus noise components aligned with these channels, are subtracted from the received spread-spectrum CDMA signal.

As is well known in the art, correlators and matched filters may be interchanged to accomplish the same function. FIGS. **1** and **3** show alternate embodiments using correlators or matched filters. The arrangements may be varied. For example, the plurality of despreading means may be embodied as a plurality of matched filters, while the channel despreading means may be embodied as a correlator. Alternatively, the plurality of despreading means may be a combination of matched filters and correlators. Also, the spread-spectrum-processing means my be embodied as a matched filter or SAW, or an EXCLUSIVE-OR gates or other devices for mixing a despread signal with a chip-code signal. As is well known in the art, any spread-spectrum despreader or demodulator may despread the spread-spectrum CDMA signal. The particular circuits shown in FIGS. **1–4** illustrate the invention by way of example.

The concepts taught in FIGS. **1–4** may be repeated, as shown in FIG. **5**. FIG. **5** illustrates a first plurality of interference cancelers **511**, **512**, **513**, a second plurality of interference cancelers **521**, **522**, **523**, through an N^{th} plurality of interference cancelers **531**, **532**, **533**. Each plurality of interference cancelers includes appropriate elements as already disclosed, and referring to FIGS. **1–4**. The input is delayed through a delay device in each interference canceler.

The received spread-spectrum CDMA signal has interference canceled initially by the first plurality of interference cancelers **511**, **512**, **513**, thereby producing a first set of estimates, i.e. a first estimate d_{11}, a second estimate d_{12}, through an N^{th} estimate d_{1N}, of the first channel, second channel through the N^{th} channel, of the spread-spectrum CDMA signal. The first set of estimates can have interference canceled by the second plurality of interference cancelers **521**, **522**, **523**. The first set of estimates d_{11}, d_{12}, . . . , d_{1N}, of the first channel, second channel through N^{th} channel, are input to the second plurality of interference cancelers, interference canceler **521**, interference canceler **522** through N^{th} interference canceler **523** of the second plurality of interference cancelers. The second plurality of interference cancelers thereby produce a second set of estimates, i.e. d_{21}, d_{22}, . . . d_{2N}, of the first channel, second channel, through N^{th} channel. Similarly, the second set estimates can pass through a third plurality of interference cancelers, and ultimately through an M^{th} set of interference cancelers **531**, **532**, **533**, respectively.

The present invention also includes a method for reducing interference in a spread-spectrum CDMA receiver having N chip-code channels. Each of the N channels is identified by a distinct chip-code signal. The method comprises the steps of despreading, using a plurality of chip-code signals, the spread-spectrum CDMA signal as a plurality of despread signal, respectively. Using a timed version of the plurality of chip-code signals, the plurality of despread signals are spread-spectrum processed with a chip-code signal corre-

sponding to a respective despread signal. Each of the N−1 spread-spectrum-processed-despread signals, is subtracted from the spread-spectrum CDMA signal, with the N−1 spread-spectrum-processed-despread signals not including a spread-spectrum-processed signal of the i^{th} despread signal, thereby generating a subtracted signal. The subtracted signal is despread to generate the i^{th} channel.

The probability of error P_e for direct sequence, spread-spectrum CDMA system is:

$$P_e = \frac{1}{2} erfc(\alpha SNR)^{\frac{1}{2}}$$

where erfc is complementary error function, SNR is signal-to-noise ratio, and $1 \leqq \alpha \leqq 2$. The value of α depends on how a particular interference canceler system is designed.

The SNR after interference cancellation and method is given by:

$$SNR = \frac{(PG/N)^{R+1}}{1 + (PG/N)^{R+1} \frac{1}{E_b/\eta} \frac{1-(N/PG)^{R+1}}{1-N/PG}}$$

where N is the number of channels, PG is the processing gain, R is the number of repetitions of the interference canceler, E_b is energy per information bit and η is noise power spectral density.

FIG. 6 illustrates theoretical performance characteristic, of the interference canceler and method for when $E_b/\eta=6$ dB. The performance characteristic is illustrated for SNR out of the interference canceler, versus PG/N. The lowest curve, for R=0, is the performance without the interference canceler. The curves, for R=1 and R=2, illustrates improved performance for using one and two iterations of the interference canceler as shown in FIG. 5. As PG/N→1, there is insufficient SNR to operate. If PG>N, then the output SNR from the interference canceler approaches E_b/η. Further, if $(N/PG)^{R+1}<<1$, then

$$SNR \rightarrow (E_b/\eta)(1-N/PG).$$

FIG. 7 illustrates the performance characteristic for when $E_b/\eta=10$ dB. FIG. 7 illustrates that three iterations of the interference canceler can yield a 4 dB improvement with PG/N=2.

FIG. 8 illustrates the performance characteristic for when $E_b/\eta=15$ dB. With this bit energy to noise ratio, two iterations of the interference canceler can yield 6 dB improvement for PG/N=2.

FIG. 9 illustrates the performance characteristic for when $R_b/\eta=20$ dB. With this bit energy to noise ratio, two iterations of the interference canceler can yield 6 dB improvement for PG/N=2. Similarly, FIGS. 10 and 11 shows that one iteration of the interference canceler can yield more than 10 dB improvement for PG/N=2.

The present invention may be extended to a plurality of interference cancelers. As shown in FIG. 12, a received spread-spectrum signal, R(t), is despread and detected by CDMA/DS detector 611. Each of the channels is represented as outputs O_{01}, O_{02}, O_{03}, . . . , O_{0m}. Thus, each output is a despread, spread-spectrum channel from a received spread-spectrum signal, R(t).

Each of the outputs of the CDMA/DS detector 611 is passed through a plurality of interference cancelers 612, 613, . . . , 614, which are serially connected. Each of the spread-spectrum channels passes through the interference canceling processes as discussed previously. The input to each interference canceler is attained by sampling and holding the output of the previous stage once per bit time. For channel i, the first interference canceler samples the output of the CDMA/DS detector at time $t=T+\tau_i$. This value is held constant as the input until $t=2T+\tau_i$ at which point the next bit value is sample. Thus, the input waveforms to the interference canceler are estimates, $d\hat{}_i(t-\tau_i)$ of the original data waveform, $d_i(t-\tau_i)$, and the outputs are second estimates, $d\hat{}\hat{}_i(t-\tau_i)$. The M spread-spectrum channel outputs O_{0i}, i=1, 2, . . . , M, are passed through interference canceler 612 to produce a new corresponding set of channel outputs O_{1i}, i=1, 2, . . . , M.

As shown in FIG. 13, the outputs of a particular spread-spectrum channel, which are at the output of each of the interference cancelers, may be combined. Accordingly, combiner 615 can combine the output of the first channel which is from CDMA/DS detector 611, and the output O_{11} from the first interference canceler 612, and the output O_{21} from the second interference canceler 613, through the output O_{N1} from the N^{th} interference canceler 614. Each output to be combined is of the corresponding bit. Therefore "s" bit time delays is inserted for each O_{S1}. The combined outputs are then passed through the decision device 616. This can be done for each spread spectrum channel, and therefore designate the outputs of each of the combiners 615, 617, 619 as averaged outputs O_1 for channel one, averaged output O_2 for channel two, and averaged output O_M for channel M. Each of the averaged outputs are sequentially passed through decision device 616, decision device 618, and decision device 620. Preferably, the averaged outputs have multiplying factor C_j which may vary according to a particular design. In a preferred embodiment, $C_j=(½)^j$. This allows the outputs of the various interference cancelers to be combined in a particular manner.

FIGS. 14–17 illustrate simulation performance characteristics for the arrangement of FIGS. 12 and 13. FIGS. 14–17 are for asynchronous channel (relative time delays are uniformly distributed between 0 and bit time, T), processing gain of 100, all user have equal powers, and thermal signal to noise ratio (E_bN of 30 dB). Length 8191 Gold codes are used for the PN sequences.

In FIG. 14, performance characteristic of each of the output stages of FIG. 12 is shown. Thus, S0 represents the BER performance at the output of CDMA/DS decoder 611, S1 represents the BER performance at the output of interference canceler 612, S2 represents the BER performance a the output of interference canceler 613, etc. No combining of the outputs of the interference cancelers are used in determining the performance characteristic shown in FIG. 14. Instead, the performance characteristic is for repetitively using interference cancelers. As a guideline, in each of the subsequent figures the output for each characteristic of CDMA/DS detector 611 is shown in each figure.

FIG. 15 shows the performance characteristic when the output of subsequent interference cancelers are combined. This is shown for a particular channel. Thus, curve S0 is the output of the CDMA/DS detector 611. Curve S1 represents the BER performance of the average of the outputs of CDMA/DS detector 611 and interference canceler 612. Here $C_0=C_1=(½)C_j=0$, j not equal to zero, one. Curve S2 represents the BER performance of the average output of interference canceler 613 and interference canceler 612. Curve S2 is determined using the combiner shown in FIG. 13. Here, C_1 and C_2 are set to equal ½ and all other C_j set to zero. Similarly, curve S3 is the performance of the output of

a second and third interference canceler averaged together. Thus, curve S3 is the performance characteristic of the average between output of a second and third interference canceler. Curve S4 is the performance characteristic of the average output of a third and fourth interference canceler. Only two interference cancelers are taken at a time for determining a performance characteristic of an average output of those to particular interference cancelers.

FIG. 16 shows the regular outputs for the CDMA/DS detector 611, and a first and second interference canceler 612, 613. Additionally, the average output of the CDMA/DS detector 611 and the first interference canceler 612 is shown as S1 AVG. The BER performance of the average of the outputs of the first interference canceler 612 and the second interference canceler 613 is shown as the average output S2 AVG.

FIG. 17 shows performance characteristic correspondence for those of FIG. 16, but in terms of signal-to-noise ratio in decibels (dB).

It will be apparent to those skilled in the art that various modifications can be made to the spread-spectrum CDMA interference canceler and method of the instant invention without departing from the scope or spirit of the invention, and it is intended that the present invention cover modifications and variations of the spread-spectrum CDMA interference canceler and method provided they come within the scope of the appended claims and their equivalents.

We claim:

1. A method of receiving spread spectrum channel signals within a spread spectrum signal comprising:

a) despreading a received spread spectrum signal for each of a plurality of specific CDMA channels to produce a first estimate for each channel;

b) for each channel, despreading the estimate obtained from the prior step for all other channels to produce despread other channel signals and subtracting the despread other channel signals from the received signal and despreading the result to produce a next estimate for each channel;

c) repeating step b a selected number of times; and

d) using the estimates for each channel produced by steps a, b and c to output a channel signal for each channel.

2. The method of claim 1 wherein step d further comprises for each channel summing the estimates produced by steps a, b and c for that channel to output the specific channels signals.

3. The method of claim 1 wherein step d further comprises for each channel multiplying each estimate produced by steps a, b and c for that channel by a factor prior to summing.

4. The method of claim 3 wherein for each channel each next estimate is multiplied by a factor with a value half of a value of a previous estimate's factor for that channel.

5. The method of claim 1 wherein each next estimate for each channel is delayed with respect to a previous estimate for that channel.

6. The method of claim 1 wherein each next estimate for each channel is delayed by a one bit time delay with respect to a previous estimate for that channel.

7. The method of claim 1 wherein step d further comprises for each channel averaging the estimates produced by steps a, b and c for that channel to output the specific channel signals.

8. The method of claim 1 wherein a number of estimates produced in steps a, b and c is at least two estimates.

9. A receiver for receiving spread spectrum channel signals within a spread spectrum signal comprising:

means for despreading a received spread spectrum signal for each of a plurality of specific CDMA channels to produce a first estimate of a series of estimates for each channel;

means for producing remaining estimates of the series for each channel by repeating a selected number of times, despreading a previous estimate for all other channels to produce despread other channels signals and subtracting the despread other channel signals from the received signal and despreading the result to produce a next estimate for each channel; and

means using the series of estimates for each channel for outputting a channel signal for each channel.

10. The receiver of claim 9 wherein said outputting means further comprises means for summing for each channel the series of estimates for that channel to output the specific channel signals.

11. The receiver of claim 10 wherein said outputting means further comprises means for multiplying for each channel the series of estimates for that channel by a factor prior to summing.

12. The receiver of claim 10 wherein said outputting means further comprises means for multiplying for each channel each next estimate for that channel by a factor with a value half of a value of a previous estimate's factor.

13. The receiver of claim 9 further comprising means for delaying each next estimate for each channel with respect to a previous estimate for that channel.

14. The receiver of claim 9 further comprising means for delaying each next estimate for a channel by a one bit time delay with respect to a previous estimate for that channel.

15. The receiver of claim 9 wherein said outputting means further comprises means for averaging for each channel the series of estimates for that channel to output the specific channel signals.

16. The receiver of claim 9 wherein the series of estimates is at least two estimates.

* * * * *

Exhibit F

US006289004B1

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Mesecher et al.

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(54) **ADAPTIVE CANCELLATION OF FIXED INTERFERERS**

(75) Inventors: **David K. Mesecher**, Huntington Station; **Fatih M. Ozluturk**, Port Washington, both of NY (US)

(73) Assignee: **InterDigital Technology Corporation**, Wilmington, DE (US)

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0684660 11/1995 (EP) H01Q/3/26

Primary Examiner—Huy D. Vu
(74) *Attorney, Agent, or Firm*—Volpe and Koenig, P.C.

(57) **ABSTRACT**

An improved base station which cancels the effects of known fixed interference sources produces a signal substantially free from the interference sources thereby increasing total channel capacity. The adaptive interference canceler system includes a main antenna for receiving signals from other communication stations and at least one directional antenna directed toward an interference source. The main and directional antennas are coupled to the adaptive canceler, which weights signals received by the directional antennas and sums the weighted signals to produce a cancellation signal. The adaptive canceler subtracts the cancellation signal from the signals received by the main antenna to provide an output signal substantially free from the interference generated by the one or more known interference sources.

4 Claims, 15 Drawing Sheets

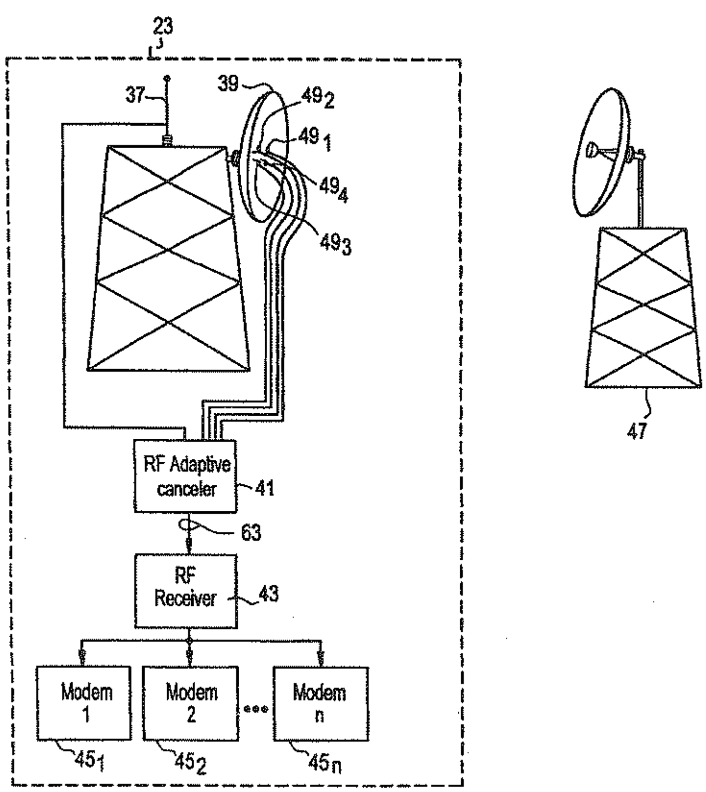


FIG.1

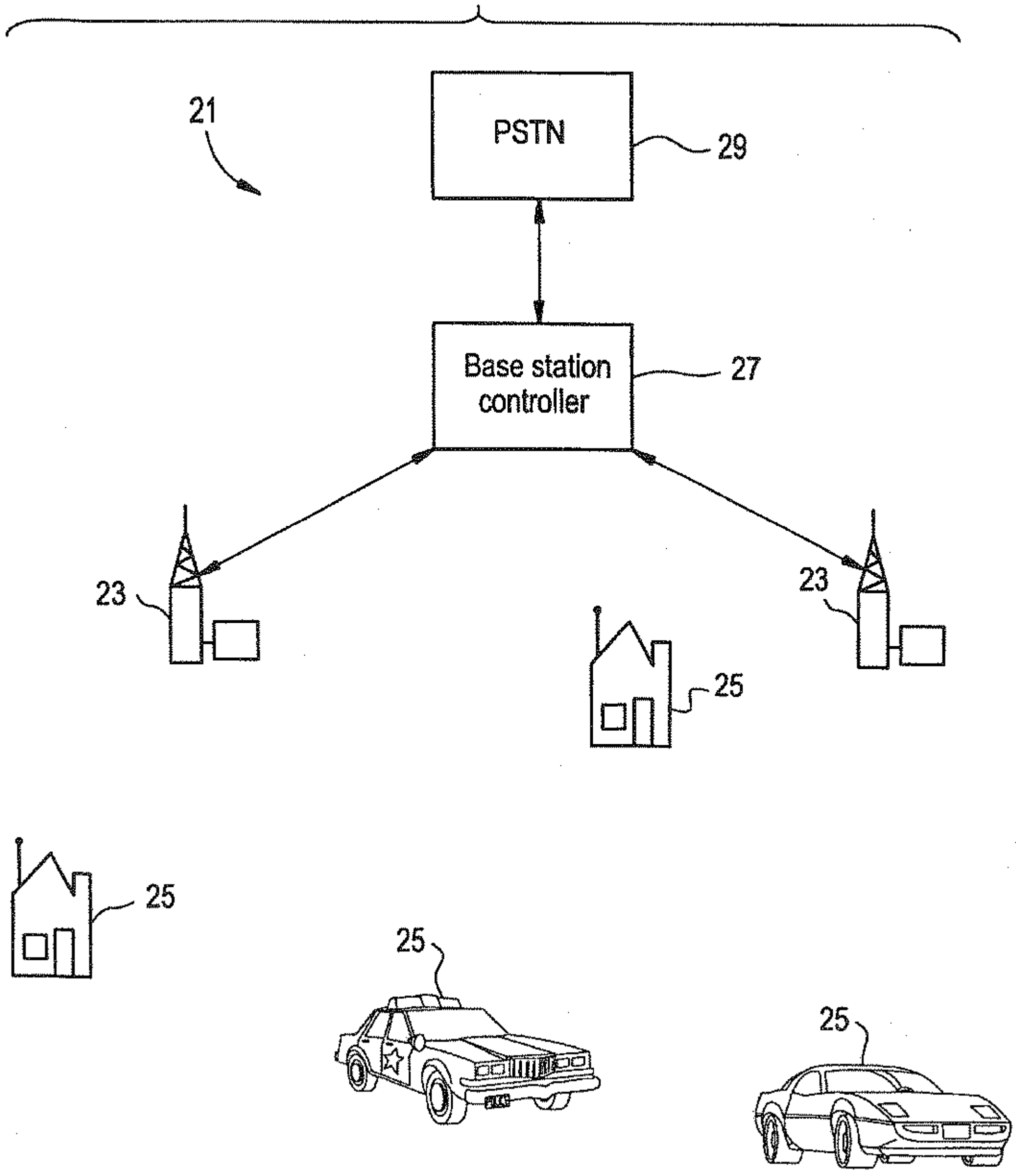


FIG.2

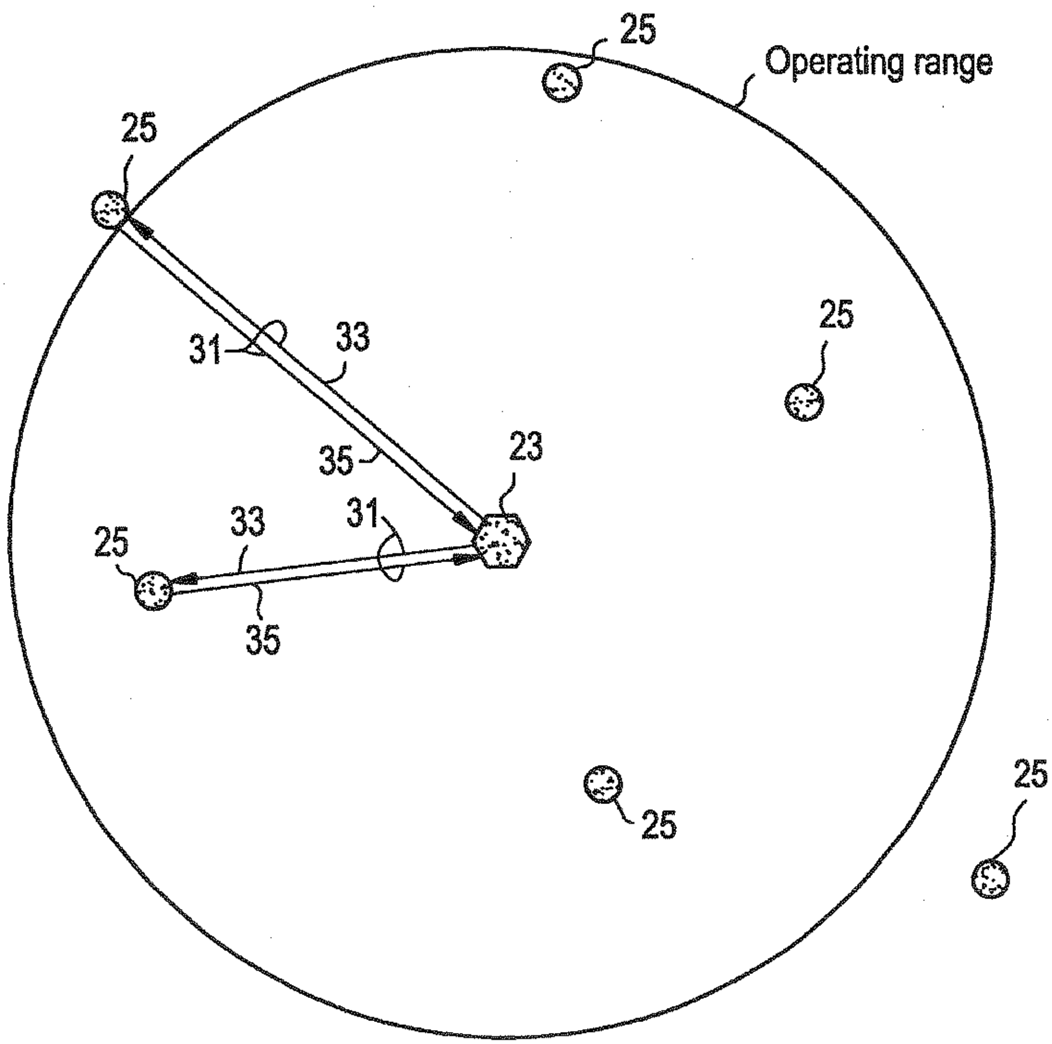
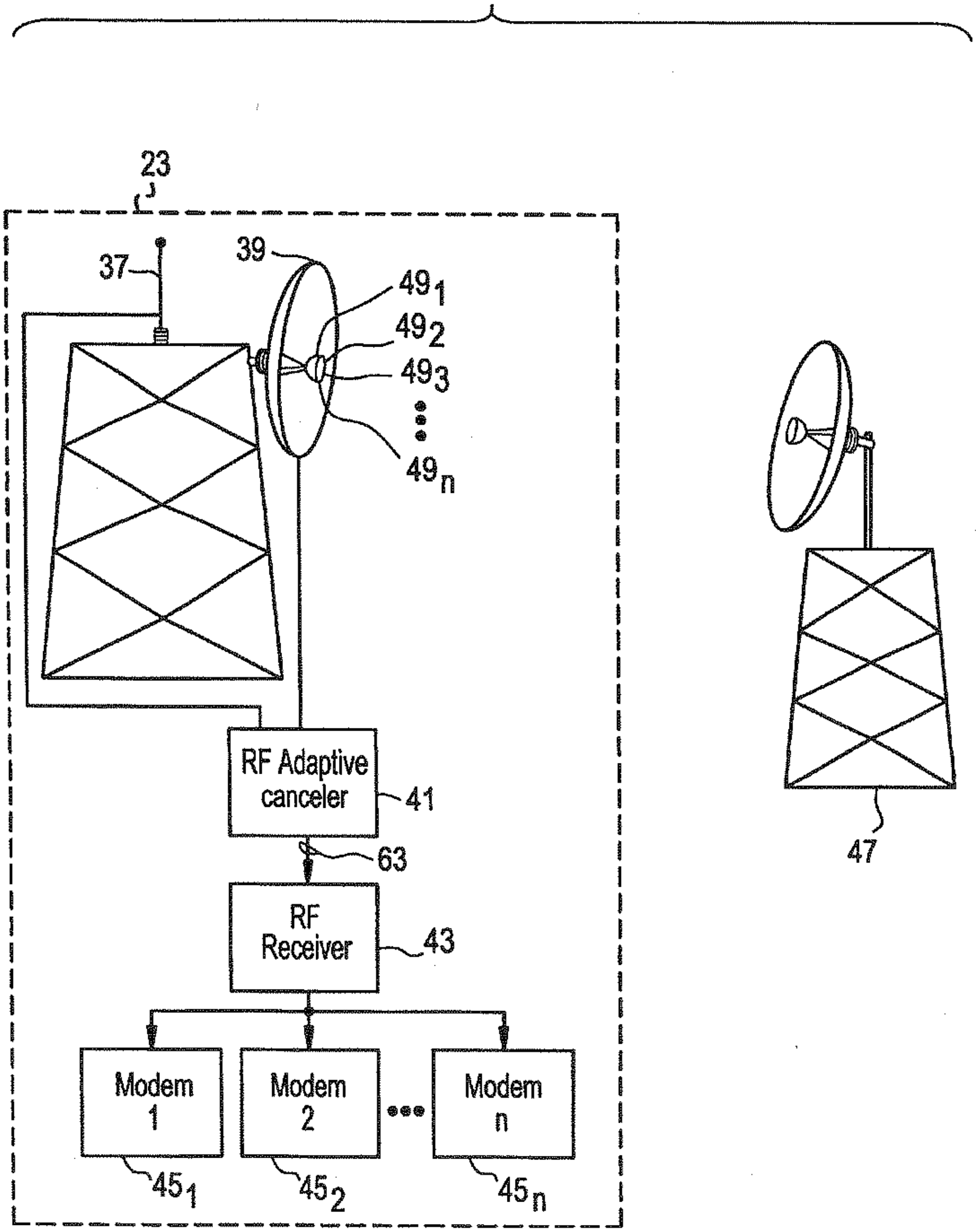


FIG.3A



23
37
39
49_1
49_2
49_3
49_n
RF Adaptive canceler
41
63
RF Receiver
43
Modem 1
Modem 2
Modem n
45_1
45_2
45_n
47

FIG.3B

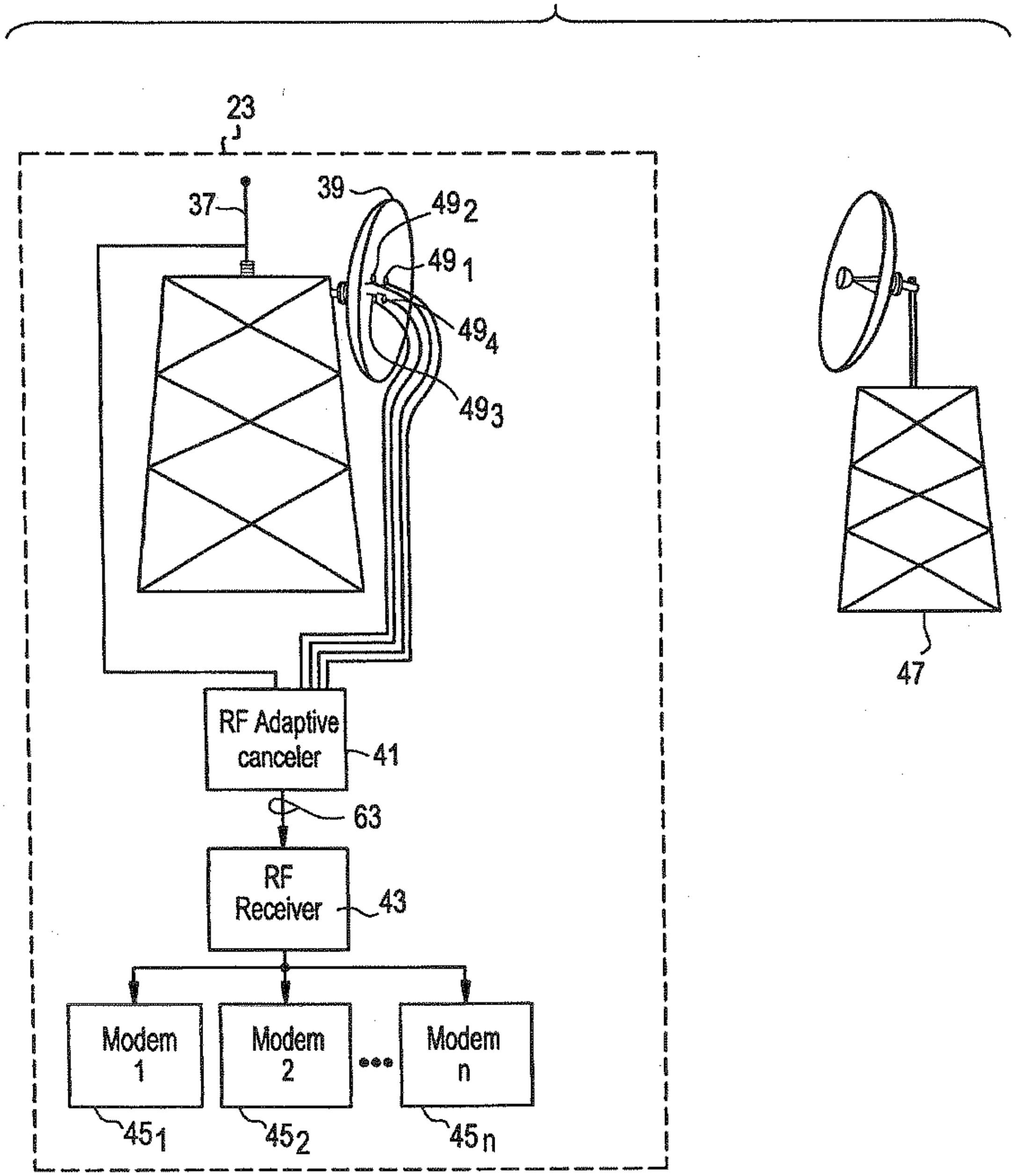
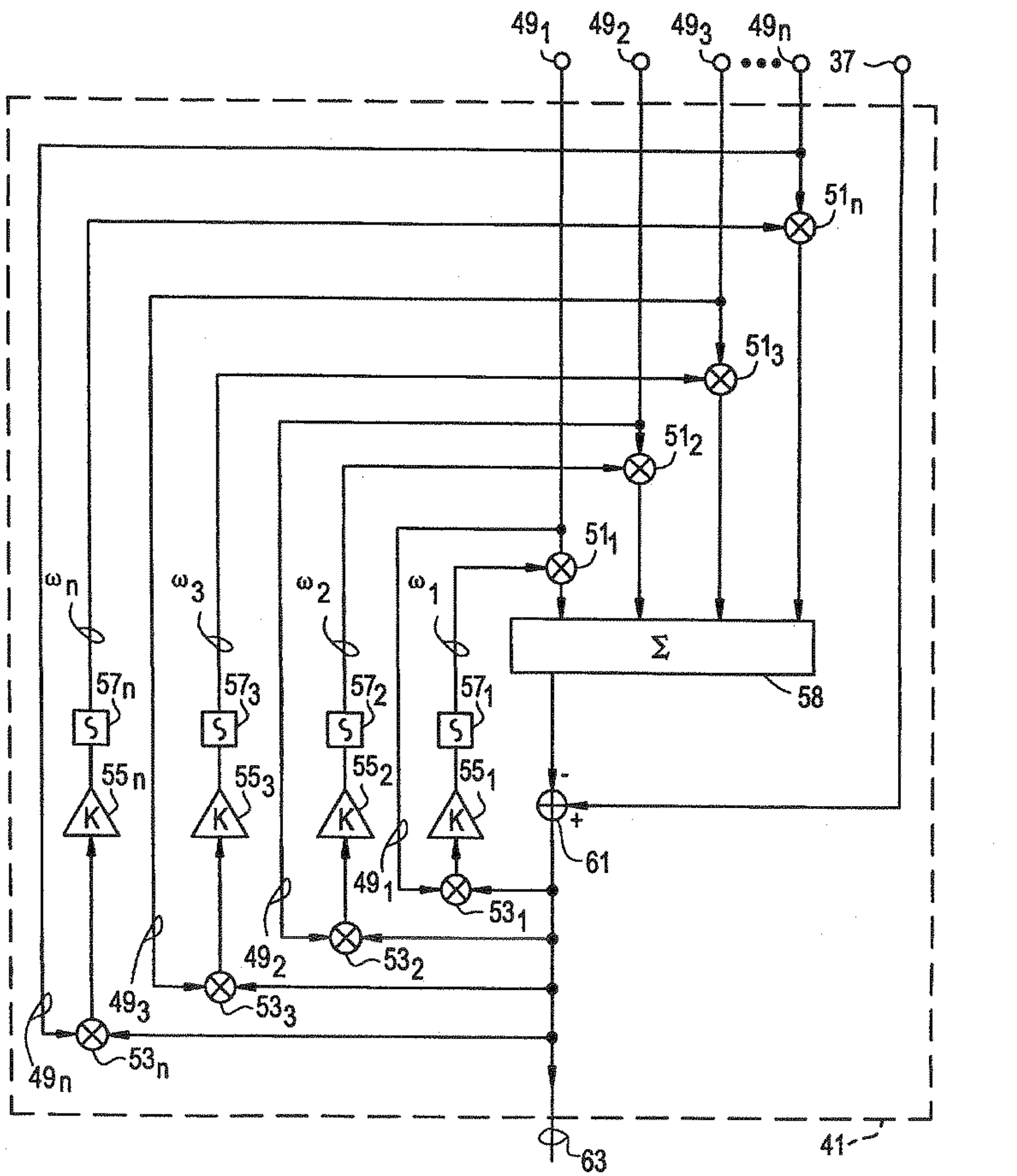

23
37
39
49_2
49_1
49_4
49_3
RF Adaptive canceler
41
63
RF Receiver
43
Modem 1
Modem 2
Modem n
45_1
45_2
45_n
47

FIG. 4



49_1
49_2
49_3
49_n
37
51_n
51_3
51_2
51_1
ω_n
ω_3
ω_2
ω_1
Σ
58
57_n
57_3
57_2
57_1
S
55_n
55_3
55_2
55_1
K
-
+
61
53_1
53_2
53_3
53_n
63
41

FIG.5

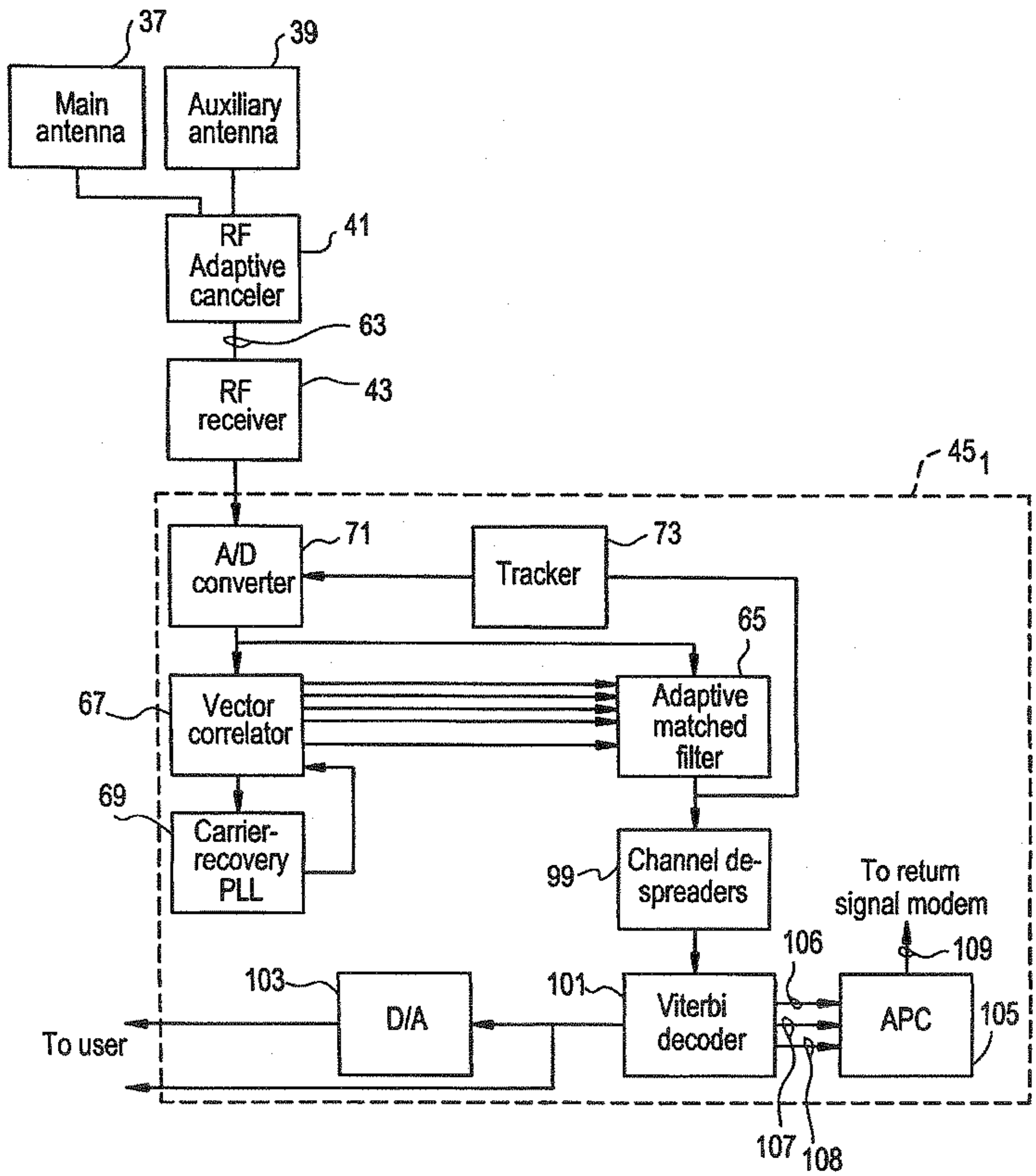

37
39
Main antenna
Auxiliary antenna
RF Adaptive canceler
41
63
RF receiver
43
45₁
A/D converter
71
Tracker
73
65
67
Vector correlator
Adaptive matched filter
69
Carrier-recovery PLL
99
Channel de-spreaders
To return signal modem
106
109
103
D/A
101
Viterbi decoder
APC
105
To user
107
108

FIG. 6

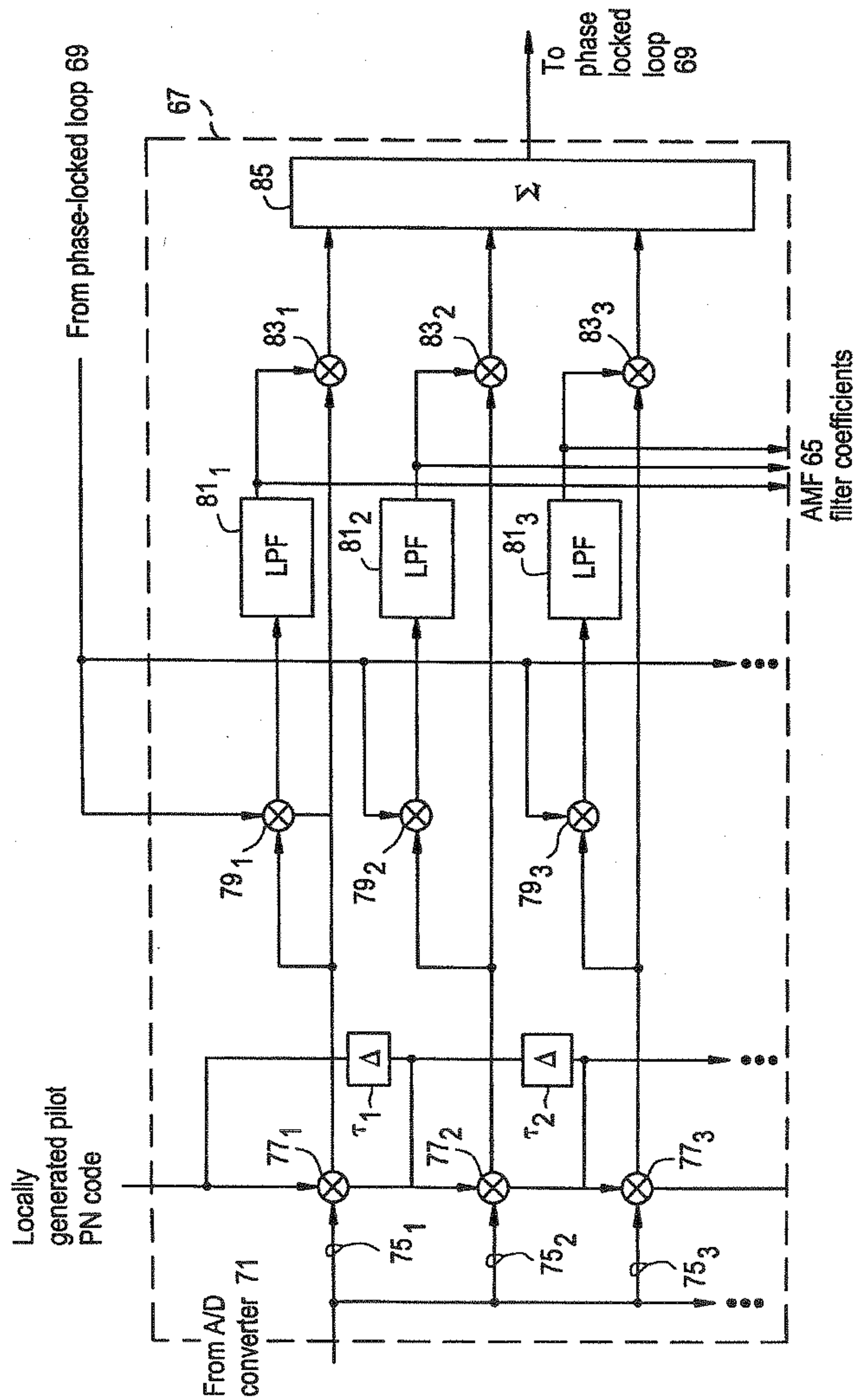

From phase-locked loop 69
67
85
Σ
To phase locked loop 69
83_1
83_2
83_3
81_1
81_2
81_3
LPF
LPF
LPF
AMF 65 filter coefficients
79_1
79_2
79_3
Δ
Δ
τ_1
τ_2
77_1
77_2
77_3
75_1
75_2
75_3
Locally generated pilot PN code
From A/D converter 71

FIG.7

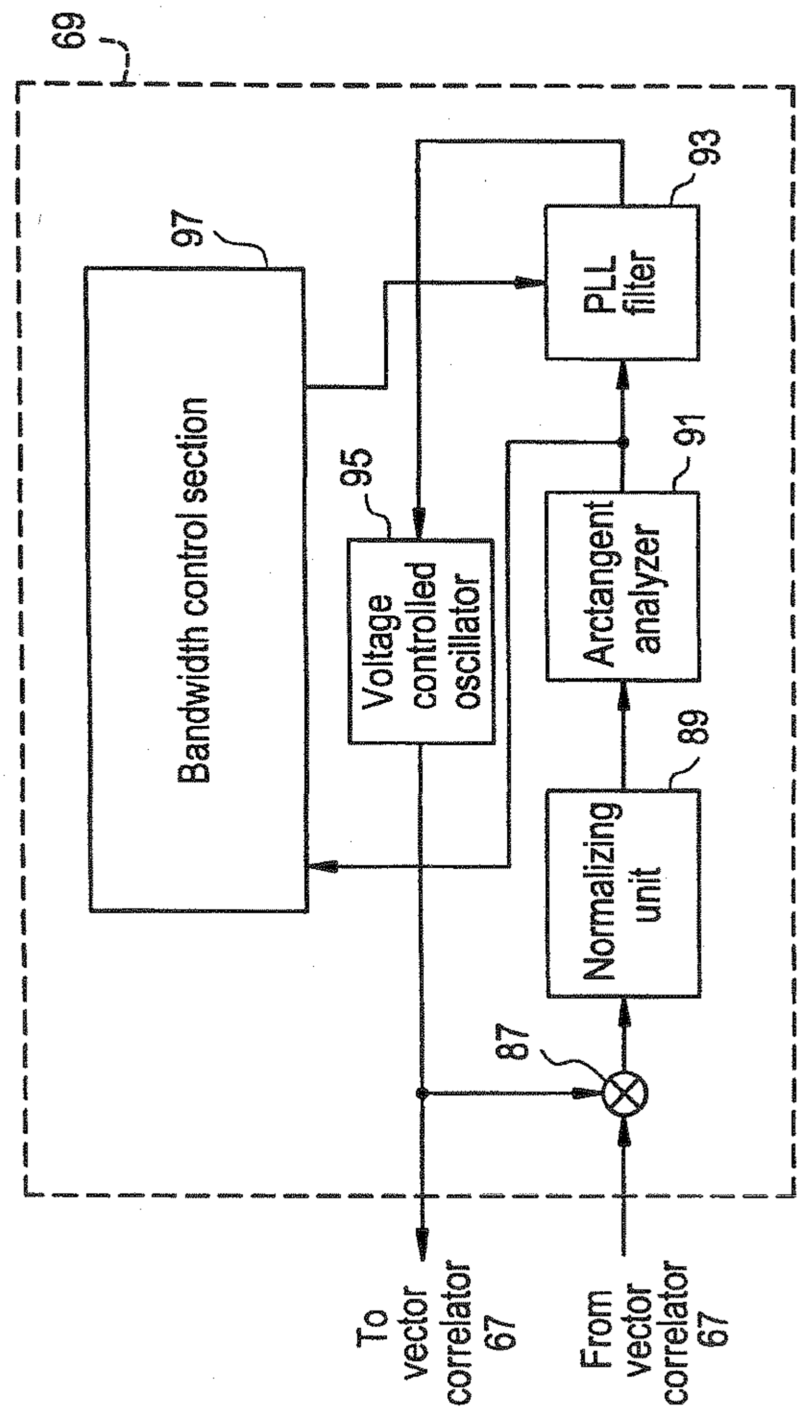

69
97
Bandwidth control section
95
Voltage controlled oscillator
93
PLL filter
91
Arctangent analyzer
89
Normalizing unit
87
To vector correlator 67
From vector correlator 67

FIG.8A

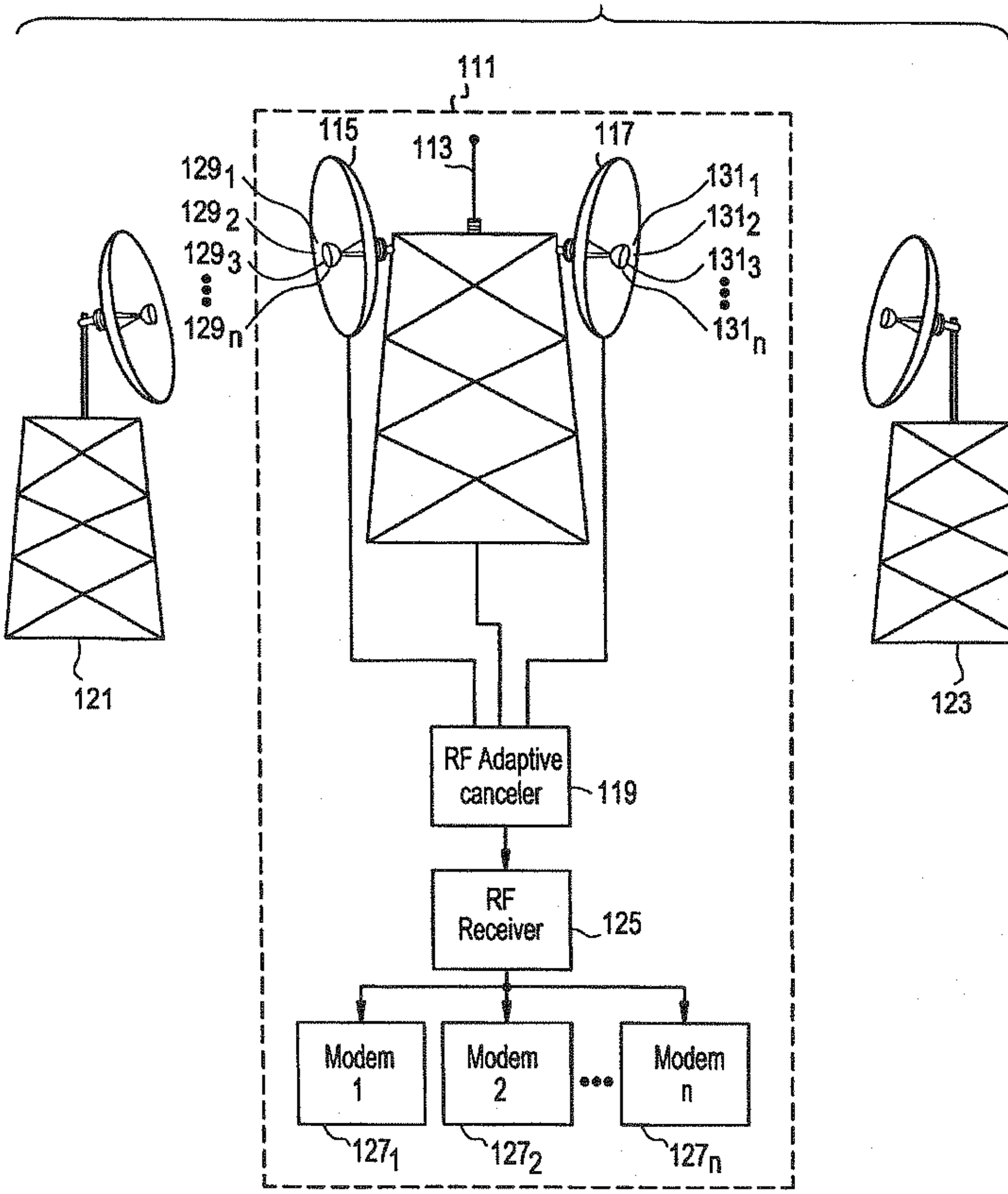
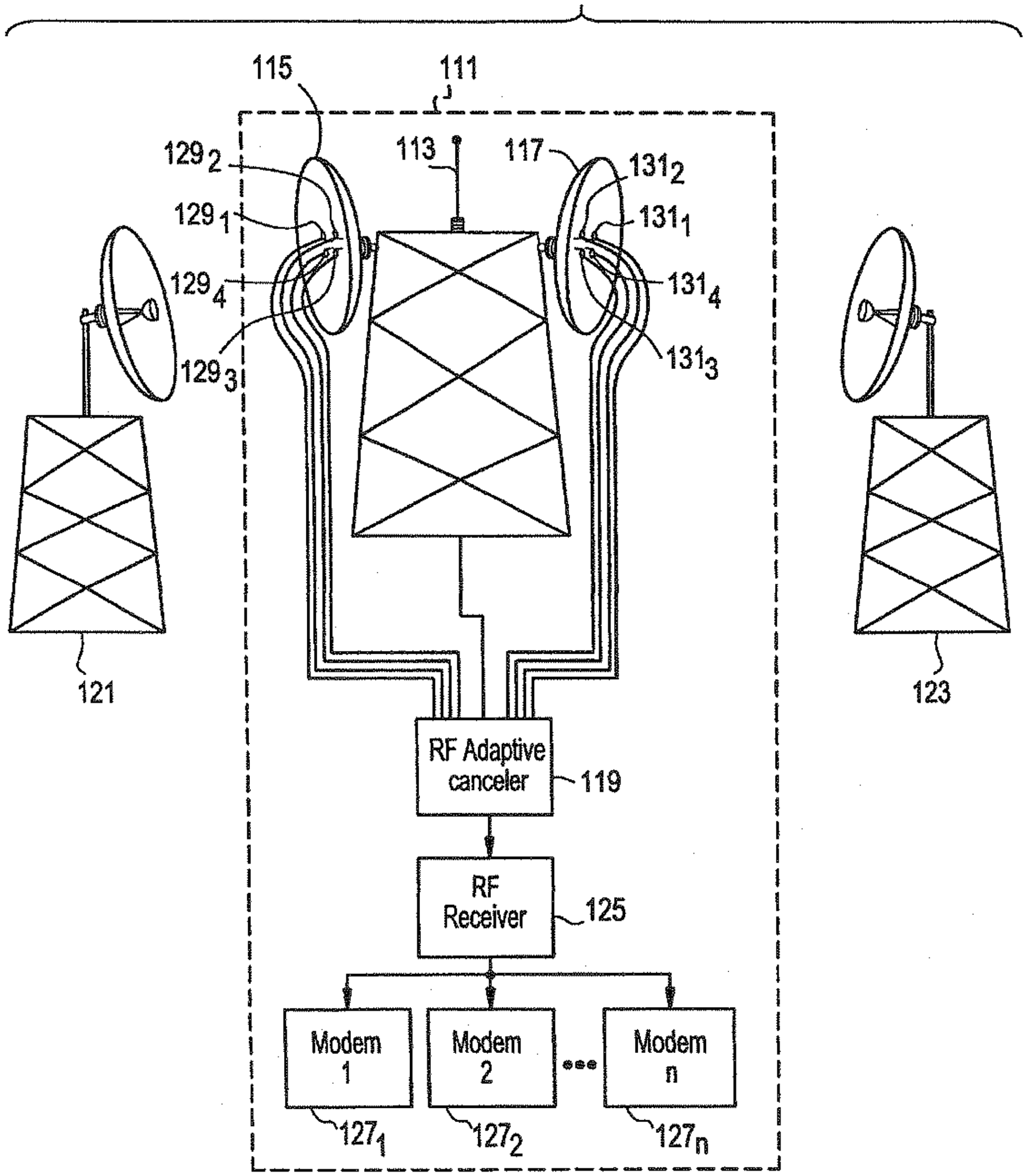

111
115
113
117
129 1
129 2
129 3
129 n
131 1
131 2
131 3
131 n
121
123
RF Adaptive canceler
119
RF Receiver
125
Modem 1
Modem 2
Modem n
127 1
127 2
127 n

FIG.8B



115
111
113
117
129_2
129_1
129_4
129_3
131_2
131_1
131_4
131_3
121
123
RF Adaptive canceler
119
RF Receiver
125
Modem 1
Modem 2
Modem n
127_1
127_2
127_n

FIG. 9

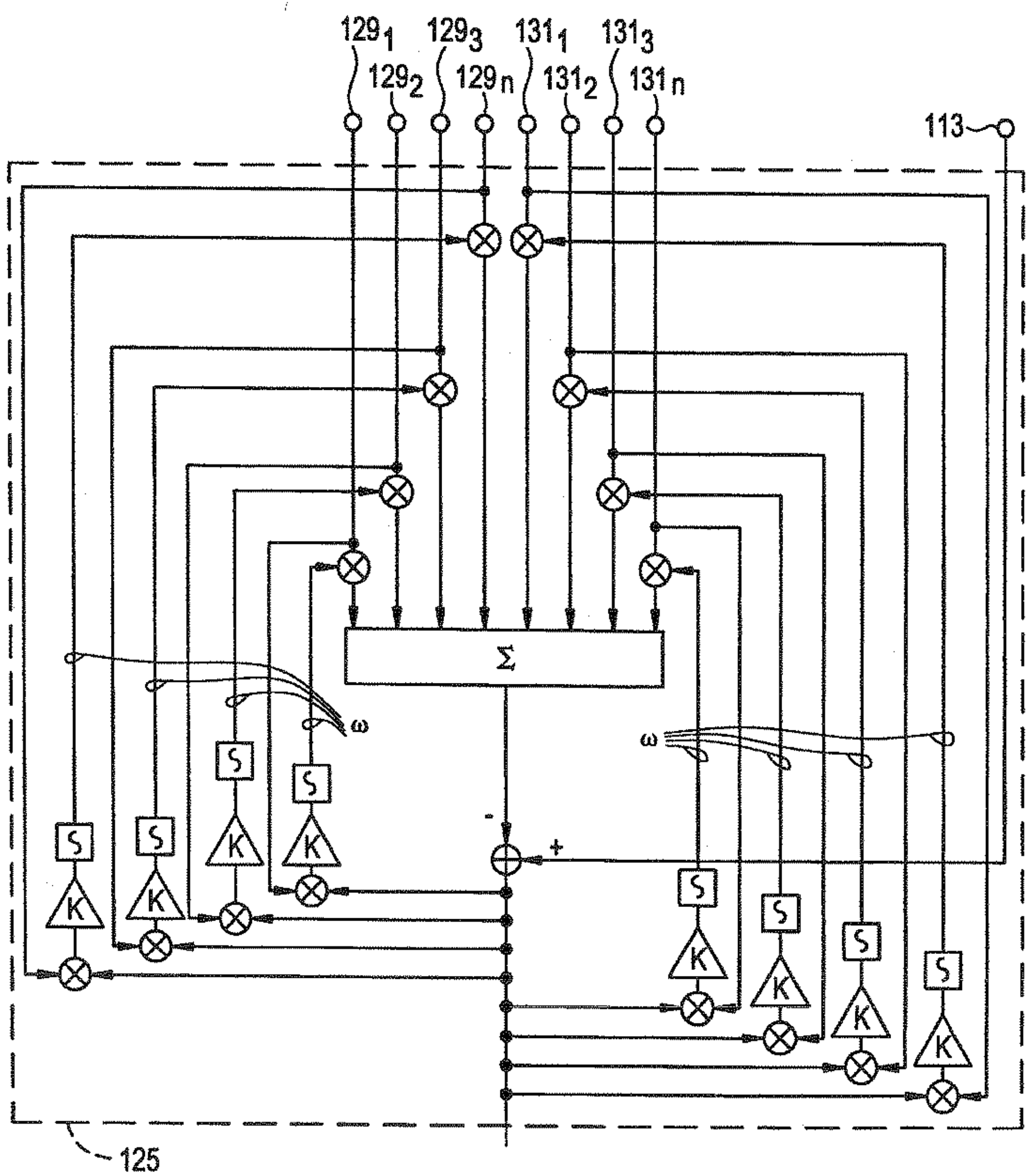


FIG. 10

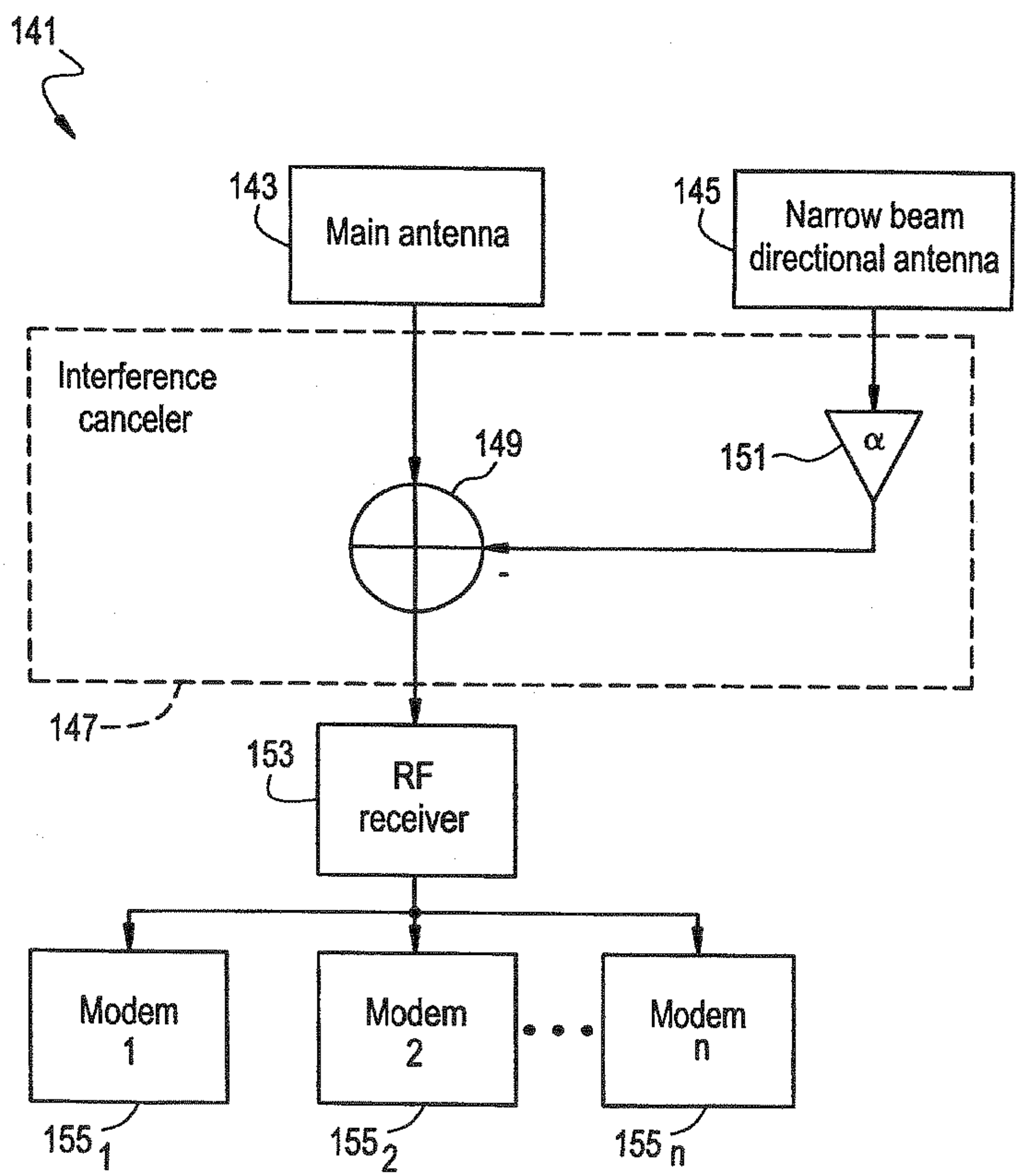

141
143
Main antenna
145
Narrow beam
directional antenna
Interference
canceler
149
151
α
-
147
153
RF
receiver
Modem
1
Modem
2
Modem
n
155 1
155 2
155 n

FIG. 11

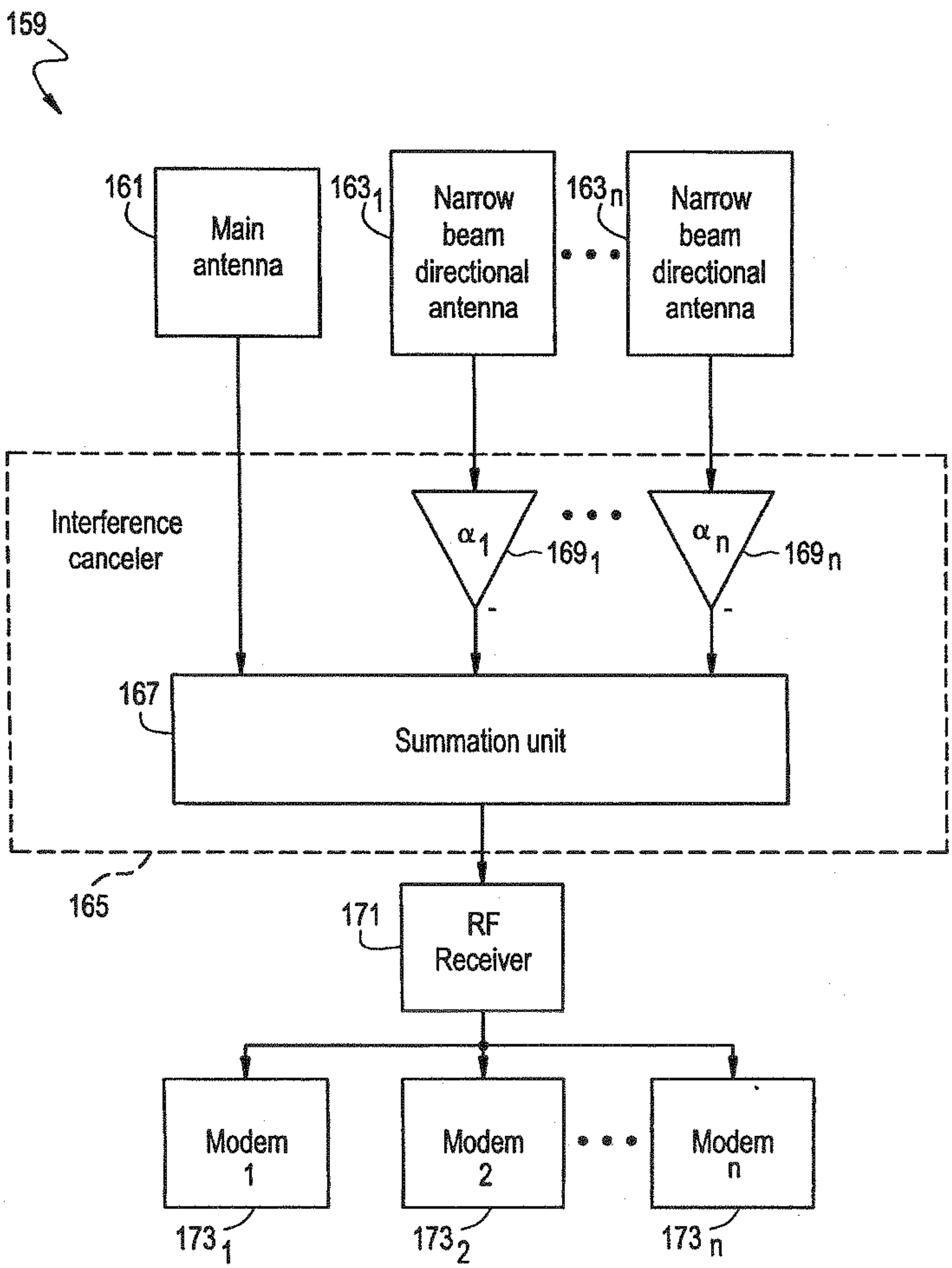

159
161
Main antenna
163_1
Narrow beam directional antenna
163_n
Narrow beam directional antenna
Interference canceler
α_1
169_1
α_n
169_n
-
-
167
Summation unit
165
171
RF Receiver
Modem 1
Modem 2
Modem n
173_1
173_2
173_n

FIG. 12

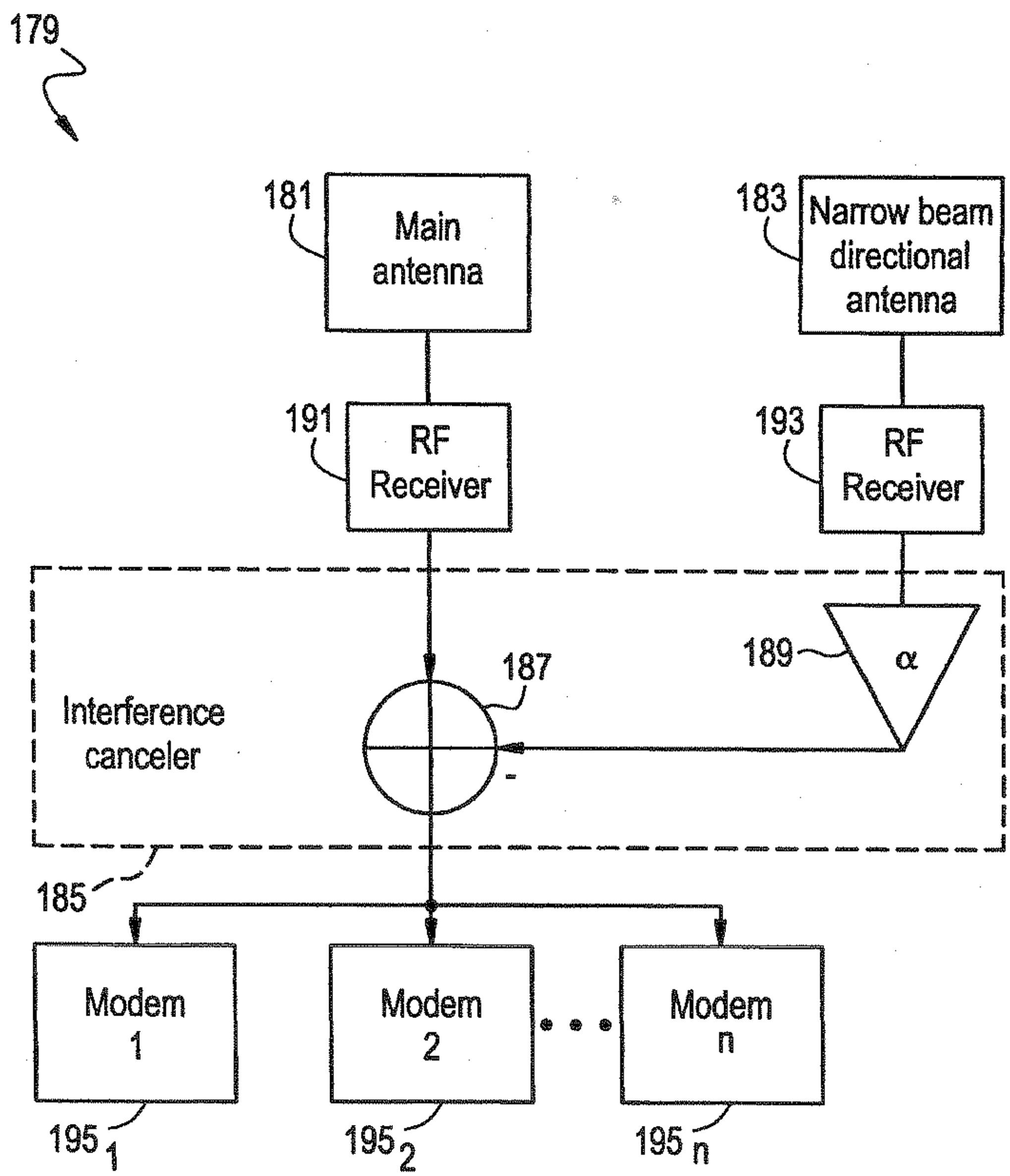
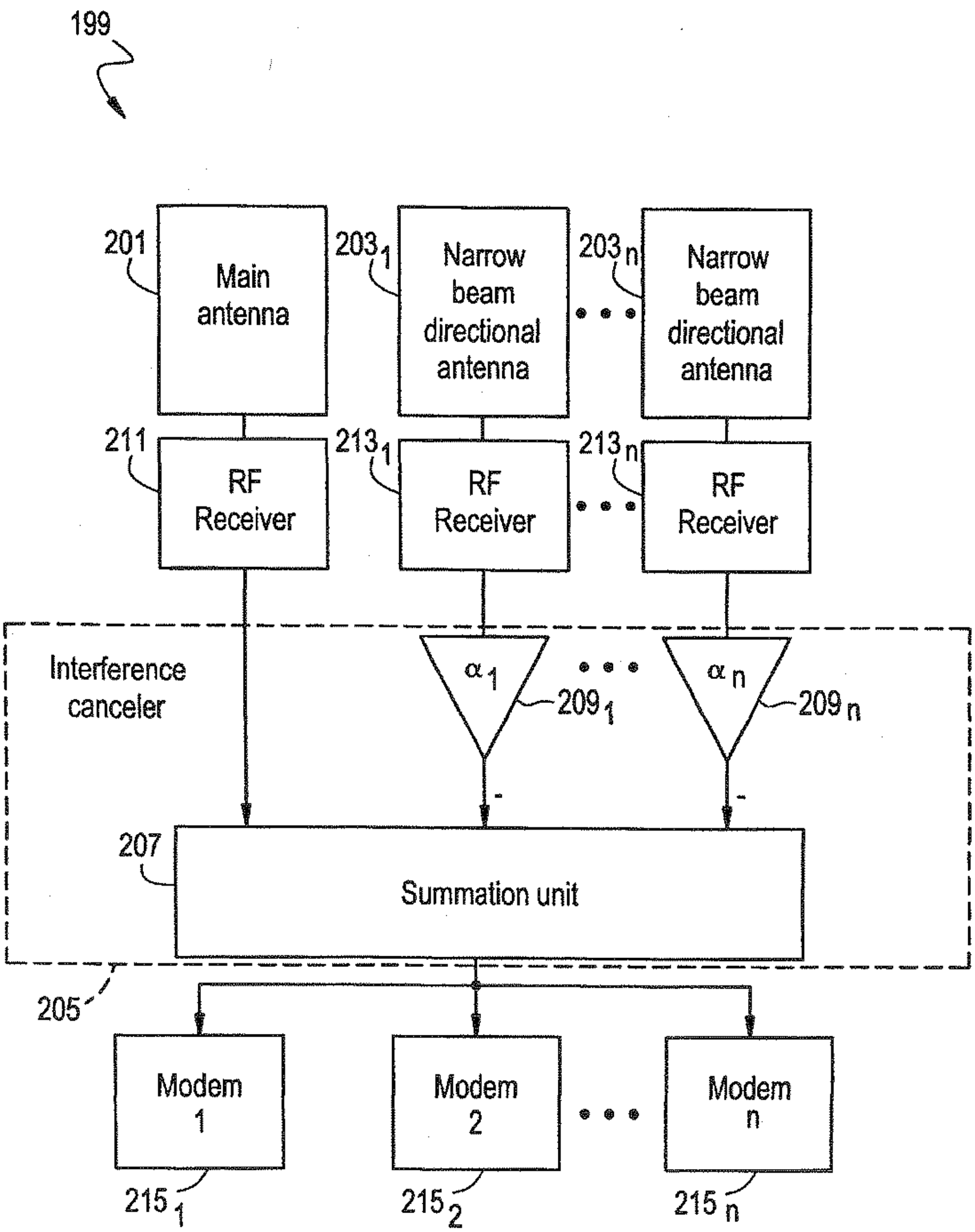

179
181
Main antenna
183
Narrow beam directional antenna
191
RF Receiver
193
RF Receiver
189
α
187
Interference canceler
-
185
Modem 1
Modem 2
Modem n
195 1
195 2
195 n

FIG. 13


199
201
Main antenna
203₁
Narrow beam directional antenna
203n
Narrow beam directional antenna
211
RF Receiver
213₁
RF Receiver
213n
RF Receiver
Interference canceler
α 1
209 1
α n
209 n
-
-
207
Summation unit
205
Modem 1
Modem 2
Modem n
215 1
215 2
215 n

ADAPTIVE CANCELLATION OF FIXED INTERFERERS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to wireless digital communication systems. More particularly, the present invention relates to an adaptive interference canceler included within telecommunication base stations and uses at least one auxiliary antenna in conjunction with a primary antenna for increasing the capacity of the telecommunication system by substantially reducing interference produced by one or more known interference sources proximate to the base station.

2. Description of the Prior Art

Over the last decade consumers have become accustomed to the convenience of wireless communication systems. This has resulted in a tremendous increase in the demand for wireless telephones, wireless data transmission and wireless access to the Internet. The amount of available RF spectrum for any particular system is often quite limited due to government regulation and spectrum allotments.

CDMA communication systems have shown promise in the effort to provide efficient utilization of the RF spectrum. At least one brand of CDMA systems, Broadband Code Division Multiple Access™ or B-CDMA™ communication systems available from InterDigital Communications Corporation, permit many communications to be transmitted over the same bandwidth, thereby increasing the capacity of the allotted RF spectrum. In B-CDMA™ communication systems, a data signal at the transmitter is mixed with a pseudorandom "spreading code" to spread the information signal across the entire transmission bandwidth or spectrum employed by the communication system. Afterwards, the spread spectrum signal is modulated with an RF carrier signal for transmission. A receiver receives the transmitted RF carrier signal and down converts the signal to a spread baseband signal. The spread data signal is despread by mixing the locally generated pseudorandom spreading code with the spread signal.

In order to detect the information embedded in a received signal, a receiver must use the same pseudorandom spreading code that was used to spread the signal. Signals which are not encoded with the pseudorandom code of the receiver appear as background noise to the receiver. However, signal frequencies within the transmission bandwidth contribute to the overall background noise making it difficult for receivers to properly detect and receive signals. A subscriber may increase the power of his transmitted signal to compensate, but overpowering interferes with the reception of other communication channels sharing the same communication bandwidth.

The allocated transmission bandwidths of many CDMA communication systems approach or share frequencies with other communication systems, such as microwave relaying or cellular communication systems. These systems may present interference signals which can greatly exceed the power of the CDMA communication signals in specific regions of the transmission bandwidth.

Applicants have recognized the need to decrease the amount of interference from identified manmade interferers in order to efficiently increase the allocated spectrum capacity of a CDMA communication system.

SUMMARY OF THE INVENTION

The present invention provides an improved base station which cancels the effects of known fixed interference

sources to produce a signal substantially free from the interference sources.

In one embodiment, an antenna system in conjunction with a base station is deployed at a location with one or more known interference sources. The antenna system includes a main antenna for receiving signals from other communication stations and at least one directional antenna directed toward an interference source. The main and directional antennas are coupled to an adaptive canceler, which weights signals received by the directional antennas and sums the weighted signals to produce a cancellation signal. The adaptive canceler subtracts the cancellation signal from the signals received by the main antenna to provide an output signal substantially free from the interference generated by the one or more known interference sources. The adaptive canceler may use a plurality of feedback loops to implement a least mean square (LMS) algorithm to properly weight the directional antenna signals.

Accordingly, it is an object of the present invention to decrease the amount of interference produced from man-made interference sources that is processed as a received CDMA communication signal.

Other advantages may become apparent to those skilled in the art after reading the detailed description of the preferred embodiment.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a communication network embodiment of the present invention.

FIG. 2 shows propagation of signals between a base station and a plurality of subscriber units.

FIG. 3A is a diagram of a base station of the present invention.

FIG. 3B is a diagram of the base station of the present invention with four coplanar feeds (n=4).

FIG. 4 is a diagram of a first embodiment of an RF adaptive canceler of the present invention.

FIG. 5 is a detailed diagram of a base station of the present invention.

FIG. 6 is a diagram of a vector correlator.

FIG. 7 is a diagram of a phase-locked loop (PLL).

FIG. 8A is a diagram of a second embodiment of a base station of the present invention.

FIG. 8B is a diagram of the second embodiment of the base station with four coplanar feeds (n=4) for both first and second auxiliary antennas.

FIG. 9 is a diagram of a second embodiment of an RF adaptive canceler of the present invention.

FIG. 10 is a diagram of a third embodiment of a base station of the present invention.

FIG. 11 is a diagram of a fourth embodiment of a base station of the present invention.

FIG. 12 is a diagram of a fifth embodiment of a base station of the present invention.

FIG. 13 is a diagram of a sixth embodiment of a base station of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Presently preferred embodiments are described below with reference to the drawing figures wherein like numerals represent like elements throughout.

A communication network 21 embodying the present invention is shown in FIG. 1. The communication network

21 generally comprises one or more base stations 23, each of which is in wireless communication with a plurality of subscriber units 25, which may be fixed or mobile. Each subscriber unit 25 communicates with either the closest base station 23 or the base station 23 which provides the strongest communication signal. The base stations 23 also communicate with a base station controller 27, which coordinates communications among base stations 23. The communication network 21 may also be connected to a public switched telephone network (PSTN) 29, wherein the base station controller 27 also coordinates communications between the base stations 23 and the PSTN 29. Preferably, each base station 23 communicates with the base station controller 27 over a wireless link, although a land line may also be provided. A land line is particularly applicable when a base station 23 is in close proximity to the base station controller 27.

The base station controller 27 performs several functions. Primarily, the base station controller 27 provides all of the operations, administrative and maintenance (OA&M) signaling associated with establishing and maintaining all of the wireless communications between the subscriber units 25, the base stations 23, and the base station controller 27. The base station controller 27 also provides an interface between the wireless communication system 21 and the PSTN 29. This interface includes multiplexing and demultiplexing of the communication signals that enter and leave the system 21 via the base station controller 27.

Referring to FIG. 2, the propagation of signals between a base station 23 and a plurality of subscriber units 25 is shown. A two-way communication path 31 comprises a forward signal 33 transmitted (TX) from the base station 23 to a subscriber 25 and a return signal received 35 (RX) by the base station 23 from the subscriber 25. The signal between the base station 23 and the subscriber 25 includes the transmission of a global pilot signal. The pilot signal is a RF modulated spreading code with no data modulation. The pilot signal is used for synchronizing the base station 23 with the subscriber 25. A communication channel is established upon synchronization.

Referring to FIG. 3A, a base station 23 of the present invention includes a main antenna 37 and an auxiliary antenna 39 which are coupled to a RF adaptive canceler 41. The output of the adaptive canceler 41 is coupled to a RF receiver 43, which is coupled to a plurality of modems 45_1–45_n. Each CDMA communication channel is spread with a unique spreading code. The plurality of modems 45_1–45_n enable simultaneous processing of multiple CDMA communications, each processing a communication associated with a different spreading code.

Signals which are not encoded with the proper pseudorandom code appear as background noise or interference to a particular communication. In addition, the level of noise may increase due to a known interferer 47. For example, a local radio station may be an interferer because it broadcasts a signal in the same transmission bandwidth used by the base station 23. To overcome the interference, the subscriber units 25 must increase their transmission power exacerbating the level of background noise since the increase in power by the subscribers 25 increases the level of noise thereby decreasing the number of subscribers 25 which can be accommodated by the base station 23.

In order to cancel the effects of the known interferer 47, the auxiliary antenna 39 is directed toward the source of interference 47. The auxiliary antenna 39 architecture is highly focused and directional such that the only large signal received by the auxiliary antenna 39 is the signal from the interferer 47 and not the signals from the subscriber units 25. The auxiliary antenna 39 has a plurality of coplanar feeds 49_1–49_n for receiving a plurality of replicas of the signal transmitted by the interferer 47. One skilled in the art should clearly recognize that the number of individual feeds used is based upon the specification of a given application. A preferred embodiment having four coplanar feeds (n=4) is shown in FIG. 3B. Referring back to FIG. 3A, each interference replica has a different phase corresponding to the coplanar feed 49_1–49_n position in free space. After the interference replicas are received through the coplanar feeds 49_1–49_n, the interference replicas are coupled to the RF adaptive canceler 41. The coplanar feeds 49_1–49_n located in the auxiliary antenna 39 are preferably spaced one-quarter to one-half wavelength of the carrier frequency apart.

Referring to FIG. 4, the RF adaptive canceler 41 removes the interference signals from the signal received by the main antenna 37 so that the overall background noise is greatly reduced. This is accomplished by providing the RF adaptive canceler 41 with circuitry for implementing a least mean square (LMS) algorithm or other adaptive algorithm to provide proper weights to each of the interference signals received by the coplanar feeds 49_1–49_n. The proper weights for each interference replica are obtained when the adaptive canceler 41 reaches steady state. These weighted interference replicas are summed to provide a combined interference signal, which is subtracted from the signal from the main antenna 37 thereby deriving a signal substantially free from the interference source 47.

The RF adaptive canceler 41 includes weighting mixers 51_1–51_n, integrating mixers 53_1–53_n, operational amplifiers 55_1–55_n, integrators 57_1–57_n, a summation unit 59, and summer 61. Weighting mixers 51_1–51_n and integrating mixers 53_1–53_n receive the interference replicas from feeds 49_1–49_n respectively. Each corresponding weighting mixer 51_1–51_n, operational amplifiers 55_1–55_n, and integrators 57_1–57_n, are operatively coupled to produce respective weights W_1–W_n which are mixed with the respective interference replica via mixers 51_1–51_n. The weights W_1–W_n are initially zero so that the interference replicas initially received pass to the summation unit 58 without adjustment. The output of the summation unit 58 is a combined interference signal and is subtracted from the total signal received from the main antenna 37 using the summer 61.

The adaptive canceler 41 outputs the received signal absent the known interference 47 to both the RF receiver 43 and the mixers 53_1–53_n to create multiple feedback loops for implementing feed 49_1–49_n weight W_1–W_n adjustments. The signals output from the integrating mixers 53_1–53_n are fed to amplifiers 55_1–55_n and integrators 57_1–57_n to adjust the weights W_1–W_n which are input to weighting mixers 51_1–51_n. The amplified and integrated signals are mixed with the interference replicas. This completes the LMS circuit. Once the signal input levels to the integrators 57_1–57_n are zero, the adaptive canceler 41 is in steady state and the weights W_1–W_n remain constant until a perturbation in the interference is experienced.

The outputs of the integrators 57_1–57_n continuously provide appropriate weights W_1–W_n via the feedback loops to the summation unit 59. The combined interference signal output from summation unit 59 is subtracted from the signal received from main antenna 37 by the summer 61, so that the signals received from the main antenna 37 are output 63 from the RF adaptive canceler 41 substantially free from the interference produced by the fixed interferer 47.

Referring back to FIG. 3A, the adaptive canceler 41 is coupled to the RF receiver 43 which demodulates the RF

signal removing the carrier frequency and outputting a baseband signal to the modems 45_1–45_n. The modems 45_1–45_n search through possible phases of the resulting baseband signal until they detect the correct phase. Phase-distorted copies of the communication signal or "multiples," are compensated for by overlaying them on the correct phase which results in increased gain. This function is performed by an adaptive matched filter (AMF) **65** which operates in conjunction with phase correcting coefficients determined by a vector correlator or rake receiver **67** with a carrier recovery phase-locked loop (PLL) **69** (FIG. **5**).

More specifically, each of the modems 45_1–45_n includes an analog-to-digital (A/D) converter **71** which quantizes the baseband signal into a digital signal with the assistance of a tracker **73**. The tracker **73** directs the A/D converter **71** to sample the strongest analog representation of the data being transmitted to the base station **23** to provide an accurate digital signal. The digital signal may include a plurality of data signals and a pilot signal.

As is well known in this art, CDMA communication units use a pilot signal to provide synchronization of a locally generated pseudorandom code with the pseudorandom code transmitted by the transmitting station, and to provide a transmission power reference during initial power ramp-up. Typically, a base station **23** transmits the pilot signal to the remote units **25** to provide synchronization of locally generated pseudorandom codes with the transmitted pseudorandom code. The pilot signal is a pseudorandom sequence of complex numbers having a magnitude (real component) of one and phase (imaginary component) of zero.

The digital pilot signal will suffer from the same distortion as the digital data signal, since they are both transmitted within the RF signal. Accordingly, the vector correlator **67**, receives the pilot signal and determines in conjunction with a phase-locked loop (PLL) **69** filter coefficients based on the distortion of the pilot signal. The derived coefficients represent the distortion or errors of the data signal. The data signal/CDMA communication signal, which is directed to the AMF **65**, is processed by the AMF **65** according to the filter coefficients generated by the vector correlator **67** in combination with the PLL **69**.

As disclosed in U.S. patent application Ser. No. 08/266,769 and U.S. patent application Ser. No. 08/871,109, which are incorporated by reference as if fully set forth herein, vector correlators in conjunction with phase-locked loop circuitry have been utilized to produce filter coefficients to correct for multipath distortion. In the present invention, the vector correlator **67** and PLL **69** generate filter coefficients associated with multipath distortion.

Referring to FIG. **6**, the vector correlator **67** provides an estimate of the complex channel impulse response, having real and imaginary components, of the bandwidth over which the CDMA communication signal is transmitted. The vector correlator **67** has a plurality of independent elements or "fingers" 75_1–75_n, preferably eleven, wherein the pseudorandom pilot signal input to each finger 75_1–75_n is delayed τ_1–τ_n by one chip to define a processing "window." A typical processing window would include eleven chips. The pilot signal is input to each element 75_1–75_n.

Each element 75_1–75_n performs an open-loop estimation of the sampled impulse response of the RF channel. Thus, the vector correlator **67** produces noisy estimates of the sampled impulse response at evenly spaced intervals. Accordingly, the signal analysis performed by the vector correlator **67** determines phase distortions occurring at different points within the processing window, for example, distortion attributable to multipath interference.

In operation, each element 75_1–75_n of the vector correlator **67** receives a locally generated pseudorandom pilot signal. The signal supplied to the vector correlator **67** from the A/D converter **71** is input to each element. Mixers 77_1–77_n mix the locally generated pilot pseudorandom code with the received signal to despread the pilot signal. The delay units τ_1–τ_n impart a one chip delay on the despread pilot signal. Each element 75_1–75_n receives a carrier offset phase correction signal from the PLL **69**, which is mixed with the despread pilot signal in each element 75_1–75_n by mixers 79_1–79_n to provide sample impulse response estimates. The vector correlator **67** further includes a plurality of low-pass filters 81_1–81_n which are coupled to each mixer 79_1–79_n to smooth each corresponding sample impulse response estimate. The complex conjugates of each smoothed sampled impulse response estimate are used as the filter coefficients, or weights, for the AMF **65**. In addition, the complex conjugate of each smoothed sampled response is mixed with the despread pilot signal by mixers 83_1–83_n. The summation unit **85** receives the outputs of mixers 83_1–83_n and outputs the combined despread pilot signal which is substantially free from multipath distortion.

The carrier recovery PLL **69** processes the output of the vector correlator **67** to estimate and correct the phase error or difference due to RF carrier signal offset. The offset may be due to internal component mismatches and/or RF distortion. Component mismatches between the subscriber oscillator and the receiver oscillator may cause slightly different oscillator outputs. These component mismatches can be further exacerbated by local and environmental conditions, such as the heating and cooling of electronic components which may affect the temperature coefficient of the various components. With respect to RF channel distortion, Doppler effects caused by the motion of the receiving stations relative to the transmitter station or a mismatched reflector may cause the RF carrier to become distorted during transmission. This may result in a RF carrier offset. The PLL **69** architecture is preferably executed in a programmable digital signal processor (DSP).

Referring to FIG. **7**, the continuously adjusted-bandwidth PLL **69** comprises a mixer **87**, a normalizing unit **89**, an arctangent analyzer **91**, a phase-locked loop filter **93**, a voltage controlled oscillator (VCO) **245** and a bandwidth control section **97**. The mixer **87** receives the output from the vector correlator **67** which is the despread pilot signal processed to correct for channel distortion due to multipath effects. The despread pilot signal is mixed with a correction signal from the VCO **95** to produce a complex error signal which is coupled to the normalizing unit **89**. The normalized signal is coupled to the arctangent analyzer **91**. The arctangent analyzer **91** outputs a phase angle derived from the complex (number) error signal. The bandwidth control section **97** continuously monitors the quantized phase error signal and generates a control signal to control the bandwidth of the phase locked-loop filter **93**. The signal output for the phase-locked loop filter **93** is transmitted to the VCO **95**. The VCO **95** outputs a feedback signal to mixer **87**. The output from phase-locked loop filter **93** indicates carrier-offset phase error. The process is repeated until a complex error signal output from the mixer **87** is at a minimum. Optimum performance of the modem **45**, will not occur until the vector correlator **67** and PLL **69** have reached a mutually satisfactory equilibrium point.

The vector correlator **67** outputs weighting coefficients to the AMF **65**. The AMF **65** processes the communication signal to compensate for channel distortion due to multipath effects. This compensation increases the gain of the signal

by, in effect, overlaying delayed replicas of the signal. The AMF 65 outputs the filtered signal to a plurality of channel despreaders 99. The despread channel signals are coupled to Viterbi decoders 101 for decoding the forward error correction (FEC) encoded data signals.

The channel despreaders 99 couple to the Viterbi decoders 101 which function as described in copending application Ser. No. 08/871,008, which is incorporated by reference as if fully set forth of the convolutional encoder (not shown) of a subscriber unit 25. The Viterbi decoders 101 decodes the FEC signal rendering the original data signal. The resulting data signal can be output either digitally or converted to analog with a digital to analog converter (DAC) 103. The Viterbi decoders 101 also perform a bit error rate (BER) 106 calculation which is coupled to an automatic power control (APC) unit 105.

The APC unit 105 determines whether the transmission signal strength of the received data signal should be increased or decreased to maintain an acceptable bit error rate based upon the estimate of the interference provided by the channel despreaders 99. The BER 106 output from the Viterbi decoder 101 is coupled to the APC unit 105 to adjust transmission power. The APC unit 105 calculates a signal-to-interference ratio (SIR_t) threshold for the system to maintain. An adjustable input representing a desired quality of service is input into the APC unit 105 as a combination of desired bit error (BER_0) 107 and signal to interference ratio (SIR_0) 108. The choice of quality depends whether the system is providing simple voice communication or a more sophisticated transmission such as facsimile. The quality determination is performed during decoding. The relationship

$$SIR_t = SIR_0 + k(BER - BER_0) \qquad \text{Eqn. 1}$$

determines SIR_t 109 which is the sought interference threshold. A weight or gain k adjusts the deviation from the desired BER_0 and derives the SIR_t from the base SIR_0 which is used to adjust transmission power. This instruction is conveyed within the reverse signal to a subscriber.

A base station 111 in accordance with a second embodiment of the present invention will be explained with reference to FIG. 8A. The base station 111 includes a main antenna 113 and first 115 and second 117 auxiliary antennas which are coupled to an RF adaptive canceler 119. The first 115 and second 117 auxiliary antennas are directed at separate known interferers 121, 123. The adaptive canceler 119 is coupled to an RF receiver 125, which is connected to a plurality of modems 127 as in the first embodiment. The RF adaptive canceler 119 cancels the effects of the two interferers. If additional known interferers are present in the operating region of main antenna 113, additional auxiliary antennas facing the additional interferers can be added to cancel the effects of the additional interferers.

The first auxiliary antenna 115 has a plurality of coplanar feeds 129_1–129_n for receiving replicas of the interference signal from the interferer 121. An embodiment having four coplanar feeds (n=4) for both first and second auxiliary antennas is shown in FIG. 8B. Referring back to FIG. 8A, the coplanar feeds 129_1–129_n are preferably one quarter to one half wavelength apart. The second auxiliary antenna 117 also has a plurality of coplanar feeds 131_1–131_n for receiving the replicas of the interference signal from the second interferer 123. The coplanar feeds 131_1–131_n are preferably a one quarter to one half wavelength apart. In addition, both first 115 and second 117 auxiliary antennas are focused such that substantially only the signals from the first 121 and second 123 interferers will be received by the auxiliary antennas respectively, and the signals from a subscriber unit 25 will not be received by the auxiliary antennas. After all the interference replicas are received through the coplanar feeds 129_1–129_n and 131_1–131_n, the replicas of the first 115 and second 117 auxiliary antennas are passed to the RF adaptive canceler 119. Each replica has a different phase corresponding to the position of each coplanar feed.

Referring to FIG. 9, an examination reveals that this embodiment 111 is the same as the adaptive canceler 41 shown in FIG. 4 with the inputs from auxiliary antenna 30 now comprising interference samples from the first auxiliary antenna 115 feeds 129_1–129_n and second auxiliary antenna 117 feeds 131_1–131_n. The adaptive canceler of the present invention can input a plurality of directional interference sources comprised of a plurality of multiphase samples and perform a uniform LMS algorithm to remove the interference samples.

Referring to FIG. 10, a third alternative embodiment of a base station 141 made in accordance with the present invention is shown. The base station 141 includes a main antenna 143 and a narrow beam directional antenna 145 (auxiliary antenna) coupled to an interference canceler 147. The interference canceler 147 includes a summer 149 and an amplifier 151. The interference cancellation method involves directing the narrow beam directional antenna 145 towards a fixed interferer (not shown) as in the previous embodiments, weighting the signal received by the narrow beam directional antenna 145 by a factor α and subtracting it from the signal received from the main antenna 143 using a summer 149. The resulting signal is used for demodulating the transmitted data. The choice of the weighting factor α determines how much reduction in the fixed interference is obtained.

The total power received by the main antenna 110 in the absence of any interference cancellation scheme is:

$$P_0 = KP + P_i \qquad \text{Eqn. 2}$$

where K equals the total number of users, P equals the power received at the base station from a user who is not in the narrow beam of the secondary antenna, and P_i is the power received from a fixed interferer.

With both the main 143 and narrow beam 145 antennas, the total power received by the main antenna 110 is

$$P_p = (K-M)P + MP^* + P_i \qquad \text{Eqn. 3}$$

where M equals the number of users within the narrow beam of the narrow beam antenna 145, and P* is the power received from a user who is in the narrow beam of a narrow beam antenna 145. The total power received by the narrow beam antenna 145 is

$$P_s = MP^* + P_i. \qquad \text{Eqn. 4}$$

The signal that is to be used in demodulation has the total power, which is

$$P_t = P_p - \alpha P_s = (K-M)P + MP^* + P_i - \alpha MP^* - \alpha P_i, \qquad \text{Eqn. 5}$$

or equivalently

$$P_t = (K-M)P + M(1-\alpha)P^* + (1-\alpha)P_i. \qquad \text{Eqn. 6}$$

As a result of the automatic power control, all users+ have the same signal strength contributing to the total power P_t.

This implies

$$P=(131\ \alpha)P^{*}, \quad \text{Eqn. 7}$$

$$P^{*}=P/1-\alpha. \quad \text{Eqn. 8}$$

Therefore, P_t can now be written as

$$P_t=KP+(1-\alpha)P_i.\text{tm Eqn. 9}$$

By comparing equation 9 to equation 3, the contribution of the fixed interferer when comparing signals received by the main antenna only to that received by the combined main-antenna auxiliary-antenna system has decreased by a factor of $(1-\alpha)$. For example, if $\alpha=0.9$, the interference has been reduced by 10 dB. Thus, there is an effective spatial attenuation in the direction of the narrow beam antenna. This attenuation will affect not only the interferer, but users that are in the narrow beam path as well. To compensate, users within the path of the narrow beam directional antenna **145** must have antenna gains that are higher by a factor of $1/(1-\alpha)$. This can be achieved by giving these particular users higher gain antennas. This is practical because there will be only a few users within the narrow beam of the narrow beam directional antenna **145**.

The weighted interference signal from amplifier **151** is subtracted from the signals received by way of main antenna **143** by summer **149** so that the signals from main antenna **143** are passed from the interference canceler **147** substantially free from the known interferers to a RF receiver **153** which demodulates and removes the carrier frequency. The baseband signal output by the RF receiver **153** is processed by the modems **155_1–155_n** as discussed in the first embodiments.

Referring to FIG. **11**, a fourth alternative embodiment of a base station **159** is shown. The base station **159** includes a main antenna **161** and a plurality of narrow beam directional antennas **163_1–163_n** (auxiliary antennas) coupled to an interference canceler **165**. The interference canceler **165** includes a summation unit **167** and a plurality of weighting amplifiers **169_1–169_n** coupled to each narrow beam directional antenna **163_1–163_n**. The interference cancellation method involves directing each narrow beam directional antenna **163_1–163_n** toward a corresponding fixed interferer as in the second alternative embodiment, weighting the signals received by the narrow beam directional antennas **163_1–163_n** by corresponding weighting factors α_1–α_n and subtracting the weighted signals from the signal received by way of the main antenna **161** using summation unit **167**. The resulting signal is then used for demodulation of user data. The choice of the weighting factors α_1–α_n determines the reduction in the fixed interference as explained in the third embodiment.

The weighted interference signals from the amplifiers **169_1–169_n** are subtracted from the signals received by the main antenna **161** by summation unit **167** so that the signals from main antenna **161** are passed from the interference canceler **165** substantially free from the known interferers to a RF receiver **171** which demodulates and removes the carrier frequency. The baseband signal output by the RF receiver **171** is processed by the modems **173_1–173_n** as discussed in the first embodiment.

Referring to FIGS. **12** and **13**, fifth **179** and sixth **199** alternative embodiments are shown similar to the architectures in FIGS. **10** and **11** differing in that the RF receivers are coupled directly to the antennas, demodulating the RF signals to baseband first and then performing the substraction of the interferers received from the narrow beam directional antennas. As one skilled in this art would recognize, the processing of the received signal and individually received interferers is at a frequency bandwidth much less than the transmission frequency bandwidth. Both the interference cancelers employed in the fifth **179** and sixth **199** alternative embodiments functions identically to those described in the third and fourth embodiments shown in FIGS. **10** and **11**.

The alternative embodiments shown in FIGS. **10**–**13** require synchronization of the received signals before subtraction can be made. This means that the cable lengths and other passive delays in the receive path of the main antenna and the auxiliary antenna(s) must be matched. The main antenna and auxiliary antenna(s) must be placed relatively close to each other to make sure that the receive signal from the antennas are not subject to different channel responses.

Although the invention has been described in part by making detailed reference to certain specific embodiments, such detail is intended to be instructive rather than restrictive. It will be appreciated by those skilled in the art that many variations may be made in the structure and mode of operation without departing from the spirit and scope of the invention as disclosed in the teachings herein.

What is claimed is:

1. An interference cancellation system for use in conjunction with a communication station having a main antenna for receiving signals from other communication stations where at least one interference source is known comprising:

a first directional antenna, having four (4) coplanar feeds, mounted proximate to said main antenna, wherein said directional antenna is directed toward a first known interference source, with said coplanar feeds being located one quarter to one half wavelength apart from each other; and

an adaptive canceler coupled to said coplanar feeds and to said main antenna for producing an output signal substantially free from interference generated by the first known interference source, wherein said adaptive canceler includes:

an output for coupling to an RF receiver of the communication station,

a cancellation unit for producing a cancellation signal by weighting the signals received by said coplanar feeds and summing said weighted signals using a least mean square (LMS) algorithm; and

a summer for summing said cancellation signal with signals received from said main antenna to produce said output signal.

2. An interference cancellation system for use in conjunction with a communication station having a main antenna for receiving signals from other communication stations wherein n interference sources are known, where n is an integer greater than 1, comprising:

first through n^{th} directional antennas, each having four (4) coplanar feeds, mounted proximate to said main antenna, wherein said directional antennas are each directed toward a respective first through n^{th} known interference source, with said coplanar feeds being located one quarter to one half wavelength apart from each other; and

an adaptive canceler coupled to said coplanar feeds and to said main antenna for producing an output signal substantially free from interference generated by the first through n^{th} known interference sources, wherein said adaptive canceler includes:

an output for coupling to an RF receiver of the communication station,

a cancellation unit for producing a cancellation signal by weighting the signals received by said coplanar feeds and summing said weighted signals using a least mean square (LMS) algorithm; and

a summer for summing said cancellation signal with signals received from said main antenna to produce said output signal.

3. A communication system including an interference cancellation system for use in conjunction with a communication station having a main antenna for receiving signals from other communication stations where at least one interference source is known comprising:

a first directional antenna, having four (4) coplanar feeds, mounted proximate to said main antenna, wherein said directional antenna is directed toward a first known interference source, with said coplanar feeds being located one quarter to one half wavelength apart from each other; and

an adaptive canceler coupled to said coplanar feeds and to said main antenna for producing an output signal substantially free from interference generated by the first known interference source, wherein said adaptive canceler includes:

an output for coupling to an RF receiver of the communication station,

a cancellation unit for producing a cancellation signal by weighting the signals received by said coplanar feeds and summing said weighted signals using a least mean square (LMS) algorithm; and

a summer for summing said cancellation signal with signals received from said main antenna to produce said output signal.

4. A communication system including an interference cancellation system for use in conjunction with a communication station having a main antenna for receiving signals from other communication stations wherein n interference sources are known, where n is an integer greater than 1, comprising:

first through n^{th} directional antennas, each having four (4) coplanar feeds, mounted proximate to said main antenna, wherein said directional antennas are each directed toward a respective first through n^{th} known interference source, with said coplanar feeds being located one quarter to one half wavelength apart from each other; and

an adaptive canceler coupled to said coplanar feeds and to said main antenna for producing an output signal substantially free from interference generated by the first through n^{th} known interference sources, wherein said adaptive canceler includes:

an output for coupling to an RF receiver of the communication station,

a canceller for producing a cancellation signal by weighting the signals received by said coplanar feeds and summing said weighted signals using a least mean square (LMS) algorithm; and

a summer for summing said cancellation signal with signals received from said main antenna.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 6,289,004 B1
DATED : September 11, 2001
INVENTOR(S) : Mesecher et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 9,
Equation 7, delete " $P = (131\alpha)P*$, " and insert therefor -- $P = (1-\alpha)P*$ --
Line 7, delete " $P_t = KP + (1-\alpha)P_i tm$ *Eqn.* 9 ", and insert therefor
-- $P_t = KP + (1-\alpha)P_i$ Eqn. 9 --

Signed and Sealed this

Nineteenth Day of March, 2002

Attest:

JAMES E. ROGAN
Director of the United States Patent and Trademark Office

Attesting Officer

US005081643A

United States Patent [19]

Schilling

[11] Patent Number: 5,081,643

[45] Date of Patent: Jan. 14, 1992

[54] SPREAD SPECTRUM MULTIPATH RECEIVER APPARATUS AND METHOD

[75] Inventor: Donald L. Schilling, Sands Point, N.Y.

[73] Assignee: SCS Mobilecom, Inc., Port Washington, N.Y.

[21] Appl. No.: 614,827

[22] Filed: Nov. 16, 1990

[51] Int. Cl.[5] H04K 1/00

[52] U.S. Cl. 375/1

[58] Field of Search 375/1

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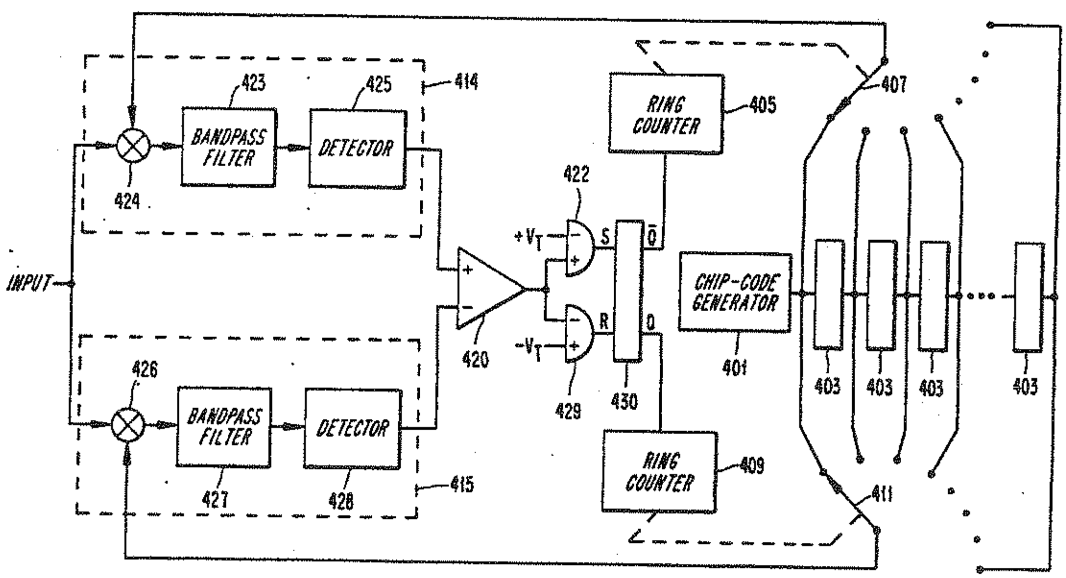
Primary Examiner—Thomas H. Tarcza
Assistant Examiner—David Cain
Attorney, Agent, or Firm—David B. Newman, Jr. & Associates

[57] ABSTRACT

An apparatus for adapting to receive a particular path, having the greatest amplitude, of a spread-spectrum signal with multipath. The spread-spectrum signal is modulated by a chip-code. A chip-code generator generates a chip-code signal having the same chip-code as the spread-spectrum signal. A plurality of shift registers shift the chip-code signal by a plurality of time delays. First and second ring counters generate first and second sequencing signals for controlling first and second switching devices. The first switching device successively switches between a plurality of taps of the shift registers in a direction of increasing or decreasing delays for generating the chip-code signal with the first time delay. The second switching device successively switches between the plurality of taps of the shift registers in a direction of increasing or decreasing delays for generating the chip-code signal with a second time delay. A first correlator correlates the spread-spectrum signal received at the input with the chip-code signal with the first time delay. A second correlator correlates the spread-spectrum signal received at the input with the chip-code signal with the second time delay. A comparator generates first and second comparator signals by comparing the outputs of the first correlator and the second correlator.

12 Claims, 3 Drawing Sheets



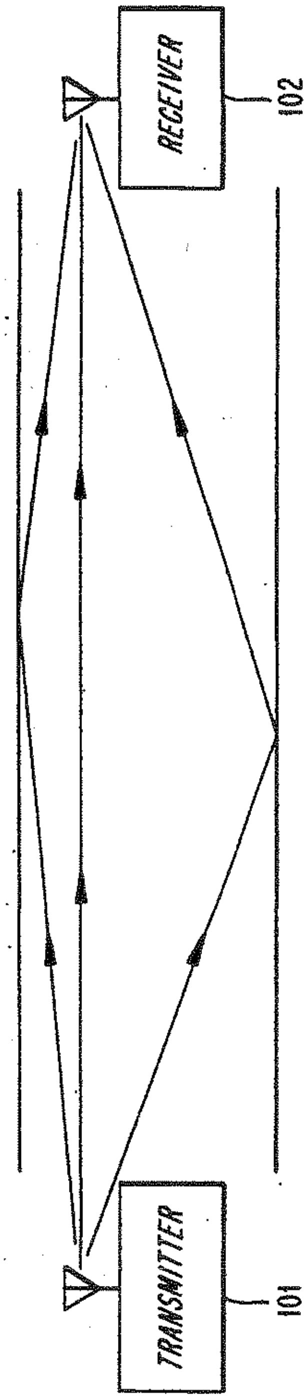


FIG. 1
(PRIOR ART)

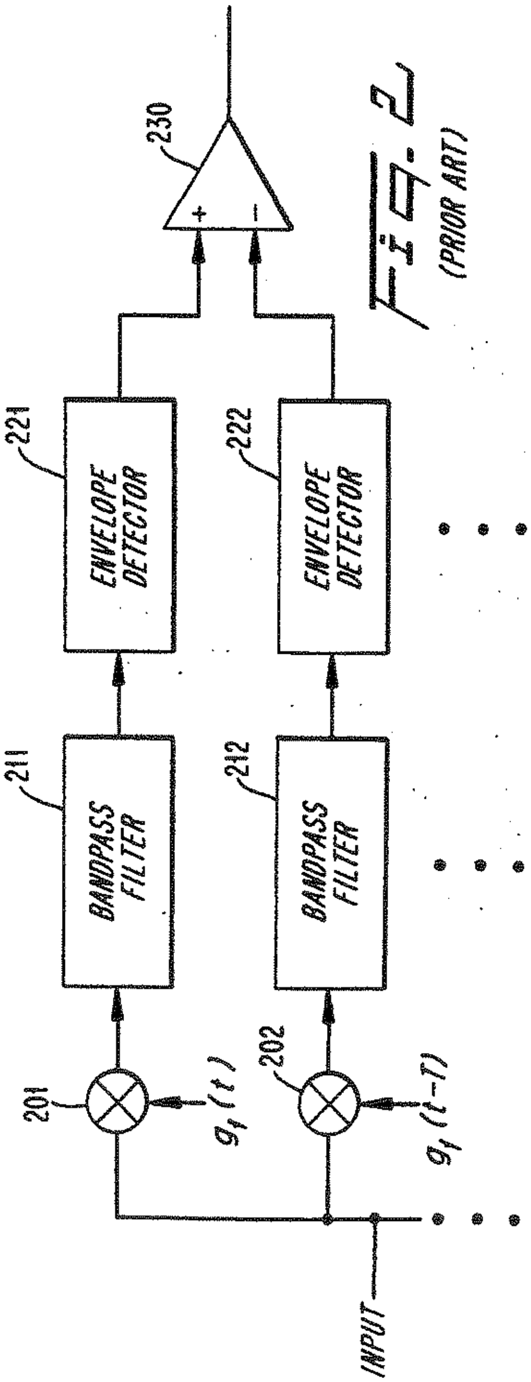


FIG. 2
(PRIOR ART)

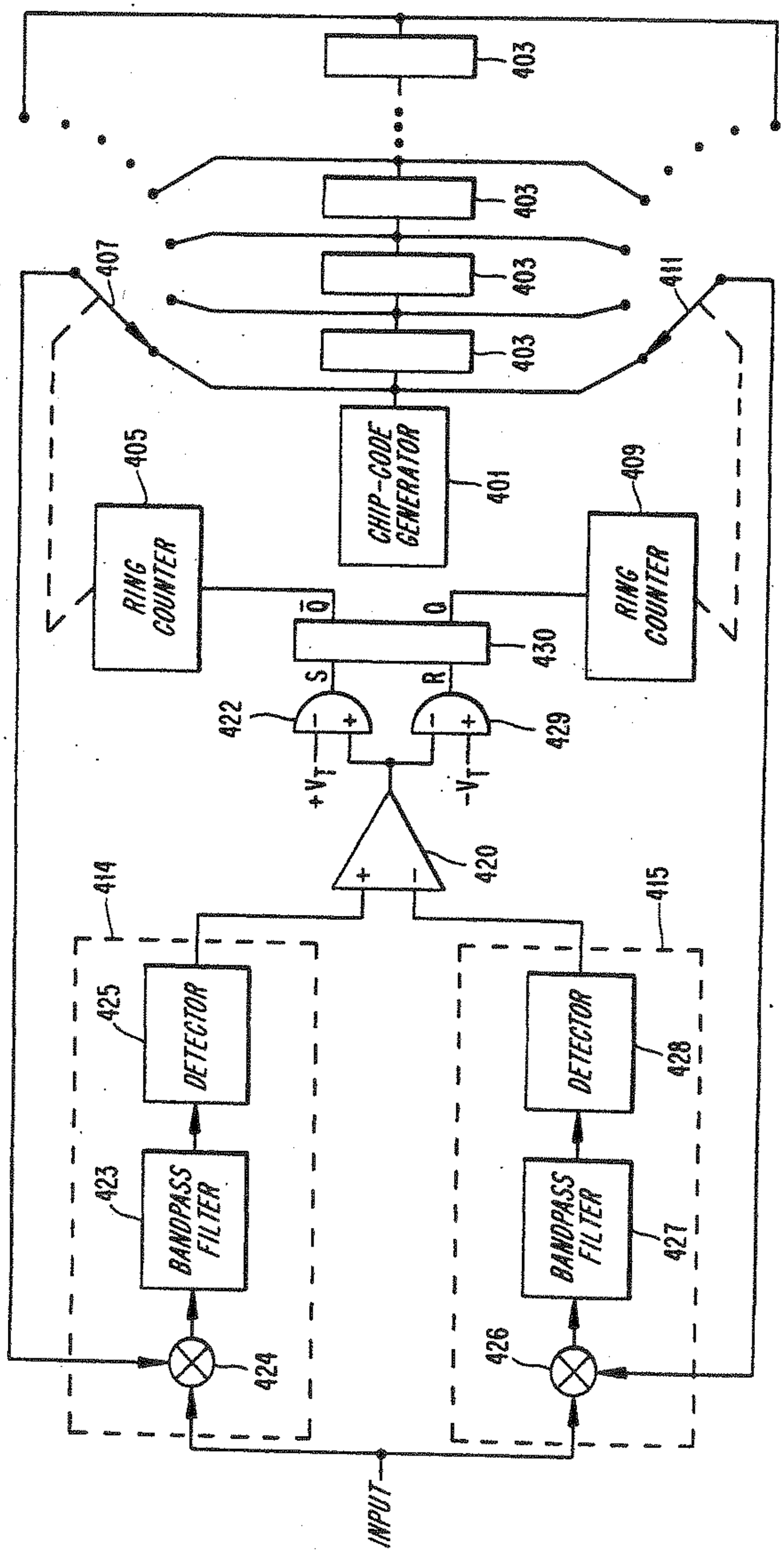
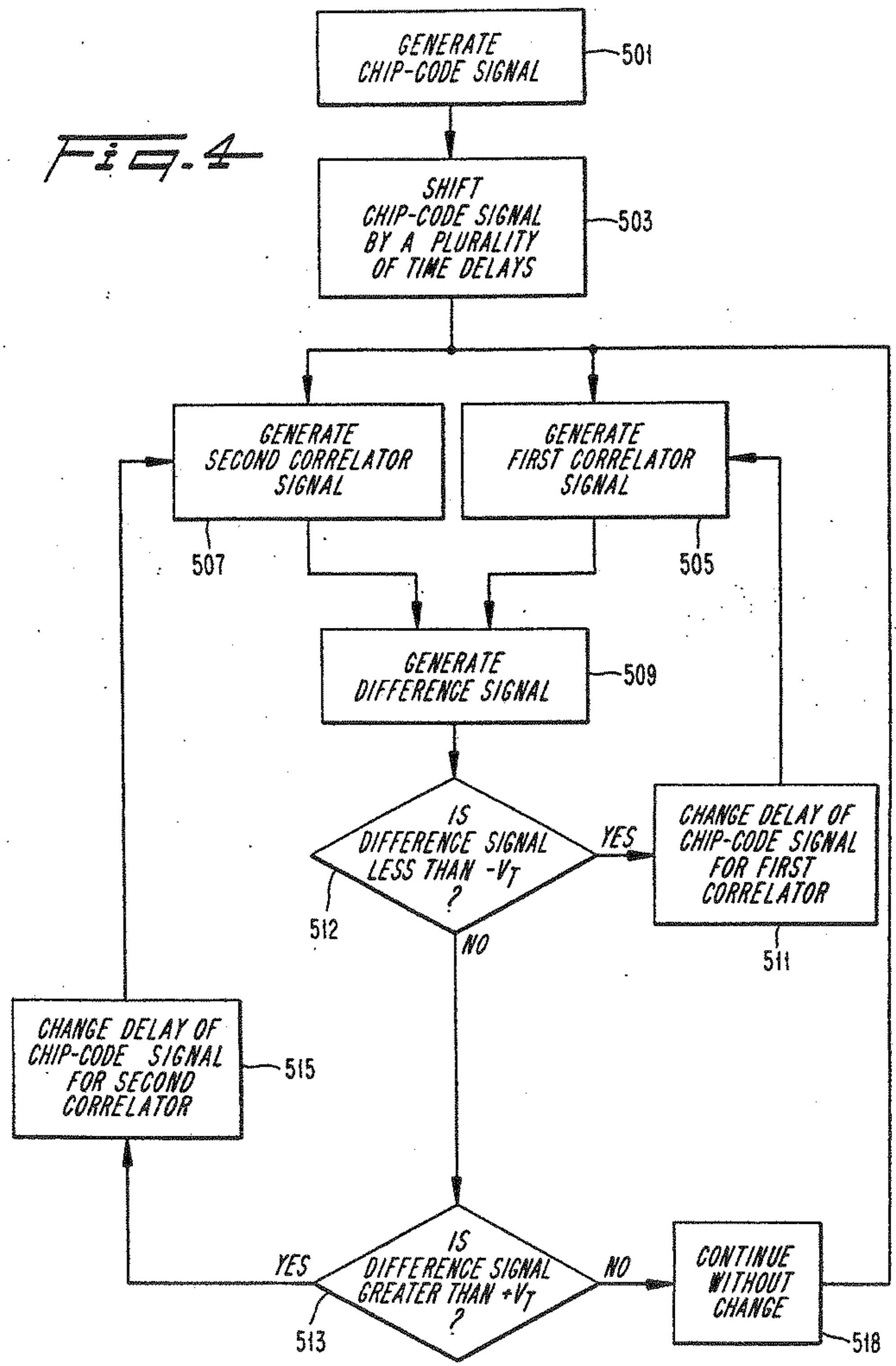

403
403
403
403
407
411
405
RING COUNTER
CHIP-CODE GENERATOR
401
409
RING COUNTER
$\bar{Q}$
Q
430
S
R
422
429
$+V_T$
$-V_T$
420
414
415
425
DETECTOR
428
DETECTOR
423
BANDPASS FILTER
427
BANDPASS FILTER
424
426
INPUT

FIG. 3

FIG. 4


GENERATE CHIP-CODE SIGNAL
501
SHIFT CHIP-CODE SIGNAL BY A PLURALITY OF TIME DELAYS
503
GENERATE SECOND CORRELATOR SIGNAL
507
GENERATE FIRST CORRELATOR SIGNAL
505
GENERATE DIFFERENCE SIGNAL
509
IS DIFFERENCE SIGNAL LESS THAN -V_T ?
512
YES
NO
CHANGE DELAY OF CHIP-CODE SIGNAL FOR FIRST CORRELATOR
511
CHANGE DELAY OF CHIP-CODE SIGNAL FOR SECOND CORRELATOR
515
IS DIFFERENCE SIGNAL GREATER THAN +V_T ?
513
YES
NO
CONTINUE WITHOUT CHANGE
518

SPREAD SPECTRUM MULTIPATH RECEIVER APPARATUS AND METHOD

BACKGROUND OF THE INVENTION

This invention relates to spread spectrum communications, and more particularly to an apparatus and method for adapting to multipath on a spread-spectrum signal.

DESCRIPTION OF THE PRIOR ART

When a signal is transmitted through a communications channel, the signal may experience multiple reflections. The multiple reflections are known as multipath. In an urban environment, and at VHF, UHF or microwave radio frequencies, the multipath may be due to multiple reflections from buildings when transmitting the signal between buildings. If a communications system were deployed inside a building, then multipath may result from multiple reflections between floors, walls and more generally, any of the structure of the building.

FIG. 1 illustratively shows a transmitter **101** transmitting through a communications channel to a receiver **102**, where the signal has a direct path and two reflected paths. The multipath results in the transmitted signal arriving at the receiver **102** with differing time delays. The differing time delays may lead to intersymbol interference, since a delayed version of the received signal may extend into a subsequent sampling interval and overlap a subsequent symbol. The multipath effect is well known in television, where it manifests itself as ghost images.

Spread-spectrum modulation offers many advantages as a communications system for an office or urban environment. These advantages include reducing intentional and unintentional interference, combating multipath problems, and providing multiple access to a communications system shared by multiple users. Commercially, these applications include, but are not limited to, local area networks for computers and personal communications networks for telephone, as well as other data applications.

A spread-spectrum signal typically is generated by modulating an information-data signal with a chip-code signal. The information-data signal may come from a data device such as a computer, or an analog device which outputs an analog signal which has been digitized to an information-data signal, such as voice or video. The chip-code signal is generated from a chip-code where the time duration, T_c, of each chip is usually substantially less than, but may be less than or equal to, the time duration of a data bit or data symbol.

Spread spectrum provides a means for communicating in which a spread-spectrum signal occupies a bandwidth in excess of, or equal to, the minimum bandwidth necessary to send the same information. The band spread is accomplished using a chip-code signal which is independent of an information-data signal. A synchronized reception with the chip-code signal at a receiver is used for despreading the spread-spectrum signal and subsequent recovery of data from the spread-spectrum signal.

Due to multipath, multiple reflections of the spread-spectrum signal arrive at a receiver with different time delays, T_i, which may be less than, greater than, or equal to the time duration, T_c, of a chip of the chip-code signal. When they occur with a time delay $T_i > T_c$ the multipath signals appear as noise to the synchronized spread-spectrum signal. One or more multipath signals, however, may have an amplitude greater than the amplitude of the spread spectrum signal to which the receiver is synchronized. Furthermore, the amplitudes of the various multipath spread spectrum signals may vary over time, since the particular path of the multipath signal having the greatest amplitude depends on receiver location and other factors. Increased receiver performance can be obtained if the receiver could adapt to receiving the particular multipath spread spectrum signal having the greatest amplitude.

For example, for a particular application, a chip may have a time duration, T_c, of 40 nanoseconds. This time duration can be less than some of the multiple time delays, T_i, of the multiple reflections of the spread-spectrum signal arriving at the receiver from multipath. For an information-data signal, $d_1(t)$, a chip-code signal, $g_1(t)$, and carrier frequency, w_o, the received spread-spectrum signal, $x_r(t)$, has the form:

$$x_r(t) = \sum_i d_1(t)[a_i g_1(t - T_i)\cos(w_o t + \theta_i)]$$

where a_i and T_i are attenuation and time duration of each path of the multipath reflections. $\theta_i = -w_o T_i$ and the

i = time delay in the data are neglected, i.e., the maximum multipath delay is assumed to be much less than the duration of a bit.

A solution to the multipath problem is to despread the received spread-spectrum signal with the chip-code signal, $g_1(t)$, using multiple delays. FIG. 2 shows an apparatus where a spread-spectrum signal from an input is despread using a plurality of product devices **201**, **202**, . . . , and a plurality of delayed chip-code signals $g_1(t)$, $g_1(t-T)$, . . . , $g_1(t-nT)$, which pass through a plurality of bandpass filters **211**, **212**, . . . , and envelope detectors **221**, **222**, . . . , respectively. The resulting outputs from the envelope detectors are compared using comparator **230**. The apparatus compares the outputs of the plurality of envelope detectors using comparator **230**, and selects the output signal with the largest signal strength.

The prior art apparatus of FIG. 2 requires a large number of correlators or bandpass filters and envelope detectors. Also, a circuit is required for selecting the output signal having the strongest signal strength.

OBJECTS OF THE INVENTION

An object of the invention is to provide an apparatus and method for receiving a particular path of a multipath spread-spectrum signal, having the greatest amplitude.

Another object of the invention is to provide a spread-spectrum apparatus and method which can adapt or select to receive a spread-spectrum signal arriving at a receiver with an arbitrary delay.

A further object of the invention is a spread-spectrum apparatus and method which adapts or compensates for multipath without requiring a large number of correlators for despreading the spread-spectrum signal.

A still further object of the invention is a spread-spectrum apparatus and method which adapts or selects to receive a particular path, having the greatest amplitude, of a spread spectrum signal with multipath, using a simple circuit for determining which of the spread-spec-

trum signals from the multipath arrives with the strongest signal strength.

An additional object of the invention is an apparatus and method for adapting or compensating for multipath on a spread-spectrum signal which is easy to implement.

SUMMARY OF THE INVENTION

According to the present invention, as embodied and broadly described herein, an apparatus for adapting or selecting to receive a particular path, having the greatest amplitude, of a spread-spectrum signal with multipath is provided comprising chip means, delay means, switching means, correlator means and comparator means. The switching means may be first switching means and second switching means, and correlator means may be first correlator means and second correlator means. The spread-spectrum signal is modulated by a chip code.

The delay means operatively is coupled to the chip means, and has a plurality of taps corresponding to a plurality of the time delays. The first switching means and the second switching means operatively are coupled to the plurality of taps of the delay means. The first correlator means operatively is coupled to the input and to the first switching means. The second correlator means operatively is coupled to the input and to the second switching means. The first correlator means and the second correlator means include product devices, bandpass filters, and detectors. The comparator means operatively is coupled between the first correlator means, the second correlator means, the first switching means and the second switching means.

The chip means generates a chip-code signal which has the same chip code as the spread-spectrum signal. The delay means shifts the chip-code signal from the chip means by a plurality of time delays, with each time delay typically having a duration equal to a time period of one chip of the chip-code signal.

The first correlator means generates the first correlation signal by correlating the spread-spectrum signal received at the input with the chip-code signal, from the first switching means. The second correlator means generates a second correlation signal by correlating the spread-spectrum signal received at the input with the chip-code signal, from the second switching means.

In response to a first correlation signal having a voltage level greater than a second correlation signal and a first threshold, the comparator means outputs a first comparator signal, which causes the second switching means to successively switch between the plurality of taps of the delay means in a direction of either increasing or decreasing delay. The first switching means outputs the chip-code signal with a first time delay. The first time delay may have any time duration from the delay means. In this state, when the first correlation signal has a voltage level less than the first threshold and second correlation signal, and greater than a second threshold, the second switching means continues switching between the plurality of taps.

In response to the first correlation signal having a voltage level less than the second correlation signal and a second threshold, the comparator means outputs a second comparator signal, which causes the first switching means to successively switch between the plurality of taps in a direction of either increasing or decreasing delay. The second switching means outputs the chip-code signal with a second time delay. The second delay may have any time duration from the delay means. In this state when the second correlation signal has a voltage level greater than the first correlation signal and the second threshold, and less than the first threshold, the first switching means continues switching between the plurality of taps.

The present invention also includes a method for adapting or selecting to receive a particular path, having the greatest amplitude, of a spread-spectrum signal with multipath. The method uses chip means, delay means, switching means, correlator means and comparator means. As set forth above, the switching means may be embodied as first switching means and second switching means, and correlator means may be embodied as first correlator means and second correlator means. The spread-spectrum signal is modulated by a chip code.

The method comprises the steps of generating with the chip means a chip-code signal having the same chip code as the spread-spectrum signal, and shifting with the delay means the chip-code signal by a plurality of time delays. The method correlates with the correlator means the spread-spectrum signal with the chip-code signal. The first correlation signal is generated from correlating the spread-spectrum signal with the chip-code signal with the first time delay, and the second correlation signal is generated from correlating the spread-spectrum signal with the chip-code signal with the second time delay. A difference signal is generated from the first correlation signal and the second correlation signal. In response to the difference signal having a voltage level greater than a first threshold, the method changes with the switching means a time delay of a chip-code signal with a second time delay and, in response to the difference signal having a voltage level less than a second threshold, the method changes with the switching means a time delay of a chip-code signal with a first time delay.

Additional objects and advantages of the invention will be set forth in part in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention. The objects and advantages of the invention also may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate preferred embodiments of the invention, and together with the description serve to explain the principles of the invention.

FIG. 1 illustrates multipath;

FIG. 2 is block diagram of a spread spectrum receiver a having envelope detectors;

FIG. 3 shows a spread spectrum receiver according to the present invention; and

FIG. 4 is a flow chart of the method of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference will now be made in detail to the present preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings, wherein like reference numerals indicate like elements throughout the several views.

As illustratively shown in FIG. 3, an apparatus for adapting or selecting to receive a particular path, hav-

ing the greatest amplitude, of a spread-spectrum signal with multipath is shown comprising chip means, delay means, switching means, correlator means and comparator means. To better understand the invention, the switching means may be considered as first switching means and second switching means, and correlator means may considered as first correlator means and second correlator means. The spread-spectrum signal is modulated by a chip-code signal.

In the exemplary arrangement shown, the chip means is embodied as chip-code generator **401**, the delay means is embodied as a plurality of shift registers **403**. The first switching means is embodied as a first ring counter **405** and a first switching device **407**. The second switching means is embodied as a second ring counter **409** and a second switching device **411**. Although shown in FIG. 3 as a rotating switch, the first switching device **407** and the second switching device **411** would be implemented using electronic circuits such as integrated circuits, microelectronic circuits, or as part of a processor chip or gate array.

The first correlator means is shown as a first correlator **414** and the second correlator means is shown as a second correlator **415**. The first correlator **414** may employ a first product device **424** coupled through a first bandpass filter **423** to a first detector **425**. The second correlator **415** may employ a second product device **426** coupled through a second bandpass filter **427** to a second detector **428**. Envelope detectors or square law detectors, by way of example, may be used for the first detector **425** and the second detector **428**. Coherent or noncoherent detectors using in-phase and quadrature-phase detection may be employed. Other circuits may be used for implementing the first correlator means and the second correlator means, as is well known in the art.

The comparator means is embodied as a differential amplifier **420**, a first comparator **422**, a second comparator **429** and flip-flop circuit **430**. Differential amplifiers, a processor or other circuits well known in the art which perform a comparing function may be employed for the comparator means.

The plurality of shift registers **403** operatively is coupled to the chip-code generator **401**. The first switching device **407** and the second switching device **411** operatively are coupled to the plurality of taps of the plurality of shift reqisters **403**. The first correlator **414** operatively is coupled to the input and to the first switching device **407**. The second correlator **415** is operatively coupled to the input and to the second switching device **411**. The differential amplifier is operatively coupled to the first correlator **414** and the second correlator **415**. The first comparator **422** operatively is coupled to differential amplifier **420** and to flip-flop circuit **430**. The second comparator **429** is operatively coupled to differential amplifier **420** and to flip-flop circuit **430**. The flip-flop circuit **430** is coupled to the first ring counter **405** and to the second ring counter **409**.

The chip-code generator **401** generates a chip-code signal having the chip code of the spread-spectrum signal. The plurality of shift registers **403** shifts the chip-code signal from the chip-code generator **401** by a plurality of time delays. The duration of a time delay may be set to any desirable length. In a typical embodiment, each time delay would have a duration equal to a time period of one chip of the chip-code signal. The plurality of shift registers **403** has a plurality of taps corresponding to each of the time delays. Five or six time delays typically may be used for a particular application, although there is no theoretical limitation.

The first correlator **414** generates a first correlation signal by correlating the spread-spectrum signal received at the input, with the chip-code signal having the first time delay. The first correlator **414** multiplies the spread-spectrum signal with the chip-code signal with the first time delay, using product device **424**, and filters and detects the product with first bandpass filter **423** and first detector **425**, respectively. Equivalent circuits for the first correlator **414** are well known in the art.

The second correlator **415** generates a second correlation signal by correlating the spread-spectrum signal received at the input, with the chip-code signal having the second time delay. The second correlator **415** multiplies the spread-spectrum signal from the input with the chip-code signal having the second time delay, using second product device **426**, and filters and detects the product with second bandpass filter **427** and second detector **428**, respectively. Equivalent circuits for the second correlator are well known in the art.

The differential amplifier **420** subtracts the second correlation signal from the first correlation signal to produce a difference signal. In response to the difference signal having a voltage level greater than a first threshold, V_T, the first comparator **422** outputs a first comparator signal. The first comparator signal may be a pulse or a voltage level which sets flip-flop circuit **430**. The output of flip-flop **430** causes the second ring counter **409** to generate a second sequencing signal. The second sequencing signal drives the second switching device **411** to successively switch between the plurality of taps of the plurality of shift registers **403** in a direction of either increasing or decreasing delay. In this state, when the difference signal has a voltage level less than the first threshold, V_T, and greater than a second threshold, $-V_T$, the flip-flop circuit **430** continues to drive the second ring counter **409** to continue outputting the second sequencing signal. Accordingly, the second switching device **411** continues to switch between the plurality of shift registers **403**, when the difference signal has a value less than the first threshold, V_T, and greater than a second threshold, $-V_T$.

The first switching device **407** continuously outputs the chip-code signal with a first time delay, while the second switching device **411** is switching between the taps of the plurality of shift registers **403**. The first time delay may have any time duration from the plurality of shift registers **403**, including a delay of zero.

In response to difference signal having a voltage level less than a second threshold, $-V_T$, the second comparator **429** outputs a second comparator signal. The second comparator signal may be a pulse or voltage level which resets flip-flop circuit **430**. The output of flip-flop circuit **430** causes the first ring counter **405** to generate a first sequencing signal. The first sequencing signal drives the first switching device **407** to successively switch between the plurality of taps in a direction of either increasing or decreasing delay. In this state, when the difference signal has a voltage level greater than the second threshold, $-V_T$, and less than the first threshold, V_T, the flip-flop circuit **430** continues to drive the first ring counter **405** to continue outputting the first sequencing signal. Accordingly the first switching device **407** continues to switch between the plurality of shift registers **403**, when the difference signal has a value greater than the second threshold, $-V_T$, and less than the first threshold, V_T.

The second switching device 411 continuously outputs the chip-code signal with the second time delay, while the first switch device 407 is switching between the tops of the plurality of shift register 403, including a delay of zero.

In a multipath application, having the first threshold set at the same value as the second threshold, such as zero volts, may be undesirable since the first comparator 422 and the second comparator 429 may continuously flip between the second ring counter 405 and the first ring counter 409. The continuous flipping between the first switching device 407 and the second switching device 411, would cause continuous adjusting the delays in the chip-code signal from the first correlator 414 and the second correlator 415.

In a preferred embodiment, the first threshold would not have the same value as the second threshold. As shown in FIG. 3, the second threshold may have a value which is the negative of the first threshold. With these threshold settings, a region exists between the first threshold and the second threshold for which the first comparator 422 and the second comparator 429 would not switch operation between the second switching device 411 and the first switching device 407. In this region the multipath is not varying enough to warrant adjusting the delay by changing switching devices.

The present invention also includes a method for adapting or selecting to receive a particular path, having the greatest amplitude, of a spread-spectrum signal with multipath. The method uses chip means, delay means, switching means, correlator means and comparator means. As set forth above, the switching means may be embodied as first switching means and second switching means, the correlator means may be embodied as first correlator means and second correlator means, and the comparator means may be embodied as first and second comparator means. The method may be implemented using integrated circuits, microelectronics, a processor chip, gate array or other devices known to a person skilled in the art. The spread-spectrum signal is modulated by a chip code.

In the exemplary flow chart of FIG. 4, the method comprises the steps of generating 501 with the chip means a chip-code signal having the chip code of the spread-spectrum signal, and shifting 503 with the delay means the chip-code signal by a plurality of time delays. The method generates 505 using first correlator means, a first correlation signal by correlating the spread-spectrum signal with the chip-code signal having a first time delay, and generates 507 using second correlator means, a second correlation signal by correlating the spread-spectrum signal with the chip-code signal having a second time delay. The method generates 509 a difference signal by subtracting the second correlation signal from the first correlation signal.

The method determines 512 whether the difference signal has a voltage level less than a second threshold, $-V_T$. If the voltage level of the difference signal is less than the second threshold, $-V_T$, then the method, using switching means, changes 511 continually the time delay of the chip-code signal having the first time delay. The chip-code signal with the second time delay is correlated with the spread-spectrum signal to generate 507 the second correlation signal. The change 511 in the first time delay may be either an increase or decrease in time delay.

If the voltage level of the difference signal is greater than a first threshold, V_T, then the method, using switching means, changes 515 the time delay of the chip-code signal with the second time delay. The chip-code signal with the first time delay is correlated with the spread-spectrum signal to generate 505 the first correlation signal. The change 515 in the second time delay may be either an increase or decrease in time delay. Otherwise, the method continues 518 without change.

If the voltage level of the difference signal is between the first threshold and the second threshold, then the switching means continues changing the time delay of the chip-code with which it was changing prior to varying between the first threshold and the second threshold. Thus, if the voltage level of the difference signal were greater than the first threshold and takes on a value between the first threshold and the second threshold, then the method continues changing the time delay of the chip-code signal having the second time delay. Similarly, if the voltage level of the difference signal were less than the second threshold and takes on a value between the first threshold and the second threshold, then the method continues to change the time delay of the chip-code signal having the first time delay.

In use, consider a spread spectrum communication system operating over a channel which has more than one path linking a transmitter to a receiver, as shown in FIG. 1. These different paths might be several discrete paths, each with a different attenuation and time delay, or a continuum of paths. The present invention, using comparator means, has the effect of selecting the output signal from first and second correlator means with the largest signal strength.

It will be apparent to those skilled in the art that various modifications can be made to the spread spectrum multipath compensation apparatus and method of the instant invention with out departing from the scope or spirit of the invention, and it is intended that the present invention cover modifications and variations of the spread spectrum multipath compensation apparatus and method provided they come in the scope of the appended claims and their equivalents.

I claim:

1. An apparatus having an input, for adapting to receive a particular path, having the greatest amplitude, of a spread-spectrum signal with multipath, said spread-spectrum signal modulated by a chip-code signal, comprising:

a chip-code generator for generating the chip-code signal having the same chip code as the spread-spectrum signal;

a plurality of shift registers operatively coupled to said chip-code generator for shifting said chip-code signal by a plurality of time delays, each time delay having a duration equal to a time period of one chip of said chip-code signal, said plurality of shift registers having a plurality of taps corresponding to each of said time delays;

a first ring counter responsive to a second comparator signal for generating a first sequencing signal;

a first switching device operatively coupled to said first ring counter and to the plurality of taps of said plurality of shift registers, said first switching device responsive to said first sequencing signal for successively switching between said plurality of taps for changing a delay of the chip-code signal with a first time delay;

a second ring counter responsive to a first comparator signal for generating a second sequencing signal;

a second switching device operatively coupled to said second ring counter and to the plurality of taps of said plurality of shift registers, said second switching device responsive to said second sequencing signal for successively switching between said plurality of taps for changing a delay of the chip-code signal with a second time delay;

a first correlator operatively coupled to said input and to said first switching device for generating a first correlation signal by correlating said spread-spectrum signal received at said input with said chip-code signal having the first time delay;

a second correlator operatively coupled to said input and to said second switching device for generating a second correlation signal by correlating said spread-spectrum signal received at said input with said chip-code signal having the second time delay;

a difference amplifier for subtracting the second correlation signal from the first correlation signal;

a first comparator operatively coupled to said difference amplifier for generating the first comparator signal when said difference signal is greater than a first threshold; and

a second comparator operatively coupled to said difference amplifier for generating the second comparator signal when said difference signal is less than a second threshold.

2. An apparatus having an input, for adapting to receive a particular path, having the greatest amplitude, of a spread-spectrum signal with multipath, said spread-spectrum signal modulated by a chip-code signal, comprising:

chip means for generating the chip-code signal having same the chip-code as the spread-spectrum signal;

delay means operatively coupled to said chip means for shifting said chip-code signal by a plurality of time delays, each time delay having a duration equal to a time period of one chip of said chip-code signal, said delay means having a plurality of taps corresponding to each of said time delays;

first switching means operatively coupled to the plurality of taps of said delay means, said first switching means responsive to a second comparator signal, for successively switching between said plurality of taps for changing a delay of the chip-code signal with a first time delay;

second switching means operatively coupled to the plurality of taps of said delay means, said second switching means responsive to a first comparator signal, for successively switching between said plurality of taps for changing a delay of the chip-code signal with a second time delay;

first correlator means operatively coupled to said input and to said first switching means for generating a first correlation signal by correlating said spread-spectrum signal received at said input with said chip-code signal having a first time delay;

second correlator means operatively coupled to said input and to said second switching means for generating a second correlation signal by correlating said spread-spectrum signal received at said input with said chip-code signal; and

comparator means operatively coupled to said first correlator means and said second correlator means for generating the first comparator signal when a difference of said first correlation signal and said second correlation signal is greater than a first threshold, and for generating the second comparator signal when a difference of said first correlation signal and said second correlation signal is less than a second threshold.

3. An apparatus having an input for adapting to receive a particular path, having the greatest amplitude, of a spread-spectrum signal with multipath, said spread-spectrum signal modulated by a chip-code signal, comprising:

chip means for generating the chip-code signal having the same chip-code as the spread-spectrum signal;

delay means for shifting said chip-code signal by a plurality of time delays, said delay means having a plurality of taps corresponding to each of said time delays;

first switching means responsive to a second comparator signal for successively switching between said plurality of taps for changing a delay of the chip-code signal with a first time delay;

second switching means responsive to a first comparator signal for successively switching between said plurality of taps for changing a delay of the chip-code signal with a second time delay;

first correlator means for generating a first correlation signal by correlating said spread-spectrum signal received at said input with said chip-code signal having a first time delay;

second correlator means for generating a second correlation signal by correlating said spread-spectrum signal received at said input with said chip-code signal; and

first comparator means for generating the first comparator signal when said first correlation signal is greater than said second correlation signal; and

second comparator means for generating the second comparator signal when said first correlation signal is less than a second correlation signal.

4. The apparatus as set forth in claim 3 wherein:

said first switching means includes a first ring counter and first switching device, said first ring counter responsive to the second comparator signal for generating a first sequencing signal and said first switching device responsive to said first sequencing signal for successively switching between said plurality of taps in a direction of decreasing or increasing delay for changing a delay of the chip-code signal with a first time delay; and

said second switching means includes a second ring counter and a second switching device, said second ring counter responsive to the first comparator signal for generating a second sequencing signal and said second switching device responsive to said second sequencing signal for successively switching between said plurality of taps in a direction of decreasing or increasing delay for changing a delay of the chip-code signal with a second time delay.

5. The apparatus as set forth in claim 3 wherein:

said first correlator means includes a first correlator, said first correlator operatively coupled to said input and to said first switching means for generating a first correlator signal by correlating said spread-spectrum signal received at said input with said chip-code signal having the first time delay; and

said second correlator means includes a second correlator, said second correlator operatively coupled to said input and to said second switching device for

generating a second correlator signal by correlating said spread-spectrum signal received at said input with said chip-code signal having the second time delay.

6. The apparatus as set forth in claim 3 wherein:

said comparator means includes a comparator, said comparator operatively coupled to said first correlator means and said second correlator means for generating the first comparator signal and the second comparator signal by comparing said first correlation signal with said second correlation signal.

7. An apparatus having an input for adapting to receive a particular path, having the greatest amplitude, of a spread-spectrum signal with multipath, said spread-spectrum signal modulated by a chip-code signal, comprising:

chip means for generating the chip-code signal having the chip code of the spread-spectrum signal;

delay means for shifting said chip-code signal by a plurality of time delays, said delay means having a plurality of taps corresponding to each of said time delays;

switching means responsive to a comparator signal having a level less than a predetermined threshold for successively switching between said plurality of taps for changing a delay of the chip-code signal with a first time delay and responsive to the comparator signal having a level greater than said predetermined threshold for successively switching between said plurality of taps for changing a delay of the chip-code signal with a second time delay;

correlator means for generating a first correlator signal by correlating said spread-spectrum signal received at said input with said chip-code signal having a first time delay and for generating a second correlator signal by correlating said spread-spectrum signal received at said input with said chip-code signal; and

comparator means for generating the comparator signal by comparing said first correlation signal with said second correlation signal.

8. The apparatus as set forth in claim 7 wherein:

said switching means includes a first ring counter, a first switching device, a second ring counter and a second switching device, said first ring counter responsive to the comparator signal having a level less than said predetermined threshold for generating a first sequencing signal and said first switching device responsive to said first sequencing signal for successively switching between said plurality of taps for changing a delay of the chip-code signal with a first time delay, said second ring counter responsive to the comparator signal having a level greater than said predetermined threshold for generating a second sequencing signal and said second switching device responsive to said second sequencing signal for successively switching between said plurality of taps for changing a delay of the chip-code signal with a second time delay.

9. The apparatus as set forth in claim 7 wherein:

said correlator means includes a first correlator and a second correlator, said first correlator operatively coupled to said input and to said switching means for generating a first correlator signal by correlating said spread-spectrum signal received at said input with said chip-code signal having the first time delay, said second correlator operatively coupled to said input and to said second switching device for generating a second correlator signal by correlating said spread-spectrum signal received at said input with said chip-code signal having the second time delay.

10. The apparatus as set forth in claim 7 wherein:

said comparator means includes a difference amplifier and first and second comparators, said difference amplifier and said first and second comparators operatively coupled to said correlator means for generating the comparator signals by comparing said first correlator signal with said second correlator signal.

11. A method using a chip-code generator, a plurality of shift registers, a first switching device, a second switching device, a first correlator, a second correlator, and a comparator, for adapting to receive a particular path, having the greatest amplitude, of a spread-spectrum signal with multipath, said spread-spectrum signal modulated by a chip-code signal, comprising the steps of:

generating with said chip-code generator the chip-code signal having the chip code of the spread-spectrum signal;

shifting with said shift registers the chip-code signal by a plurality of time delays;

changing with said first switching device, in response to a second comparator signal, a time delay of the chip-code signal with a first time delay;

changing with said second switching device, in response to a first comparator signal, a time delay of the chip-code signal with a second time delay;

correlating with said first correlator the spread-spectrum signal with the chip-code signal with the first time delay;

correlating with said second correlator the spread-spectrum signal with the chip-code signal with the second time delay; and

comparing with said comparator a first correlation signal from said first correlator with a second correlator signal from said second correlator and first and second thresholds to generate the first and second comparator signals.

12. A method using chip means, delay means, switching means, correlator means and comparator means, for adapting to receive a particular path, having the greatest amplitude, of a spread-spectrum signal with multipath, said spread-spectrum signal modulated by a chip-code signal, comprising the steps of:

generating with said chip means the chip-code signal having the chip code of the spread-spectrum signal;

shifting with said delay means the chip-code signal by a plurality of time delays;

changing with said switching means, in response to a comparator signal having a level less than a predetermined threshold, a time delay of the chip-code signal with a first time delay;

changing with said switching means, in response to the comparator signal having a level greater than a predetermined threshold, a time delay of the chip-code signal with a second time delay;

correlating with said correlator means the spread-spectrum signal with the chip-code signal with the first time delay;

correlating with said correlator means the spread-spectrum signal with the chip-code signal with the second time delay; and

comparing the a signal from said first correlator with a second correlation signal from said second correlator to generate the comparator signals.

* * * * *

Exhibit R

US005673286A

United States Patent [19]

Lomp

[11] Patent Number: 5,673,286

[45] Date of Patent: Sep. 30, 1997

[54] SPREAD SPECTRUM MULTIPATH PROCESSOR SYSTEM AND METHOD

[75] Inventor: Gary R. Lomp, Centerport, N.Y.

[73] Assignee: InterDigital Technology Corporation, Wilmington, Del.

[21] Appl. No.: 423,513

[22] Filed: Apr. 17, 1995

Related U.S. Application Data

[62] Division of Ser. No. 368,710, Jan. 4, 1995.

[51] Int. Cl.[6] H04K 1/00

[52] U.S. Cl. 375/208; 375/200; 375/207

[58] Field of Search 375/200, 207, 375/208, 343, 349; 455/133, 134, 135, 137

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Primary Examiner—Stephen Chin
Assistant Examiner—T. Ghebretinsae
Attorney, Agent, or Firm—David Newman & Associates, P.C.

[57] ABSTRACT

A spread-spectrum system and method for providing high capacity communications through multipath compensation. A multipath processor including a first plurality of correlators, a second plurality of correlators, a first adder, a second adder, and a selector device or a combiner device is provided for tracking a spread-spectrum signal arriving in a plurality of groups. The first plurality of correlators despreads a first group of spread-spectrum signals as a first group of despread signals which are added by the first adder to generate a first combined-despread signal. The second plurality of correlators despreads a second group of spread-spectrum signals as a second group of despread signals which are added by the second adder to generate a second combined-despread signal. The selector device selects either the first or the second combined-despread signal and outputs the selected signal. Alternatively, the combiner device combines the first and the second combined-despread signals and outputs the combined signal.

24 Claims, 23 Drawing Sheets

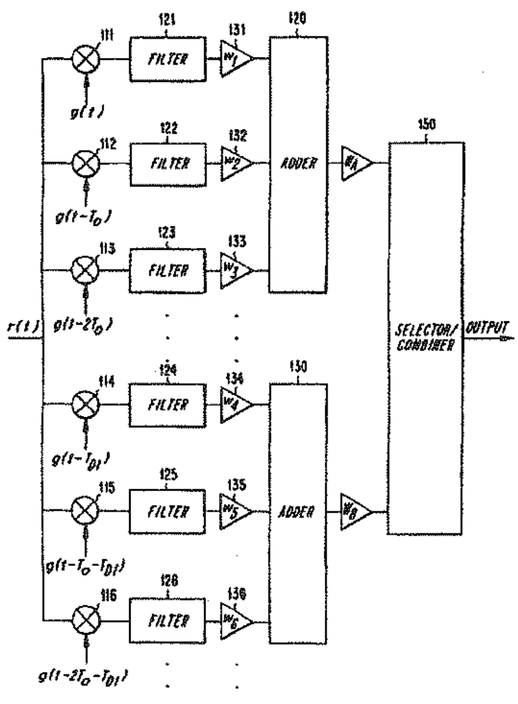


FIG. 1

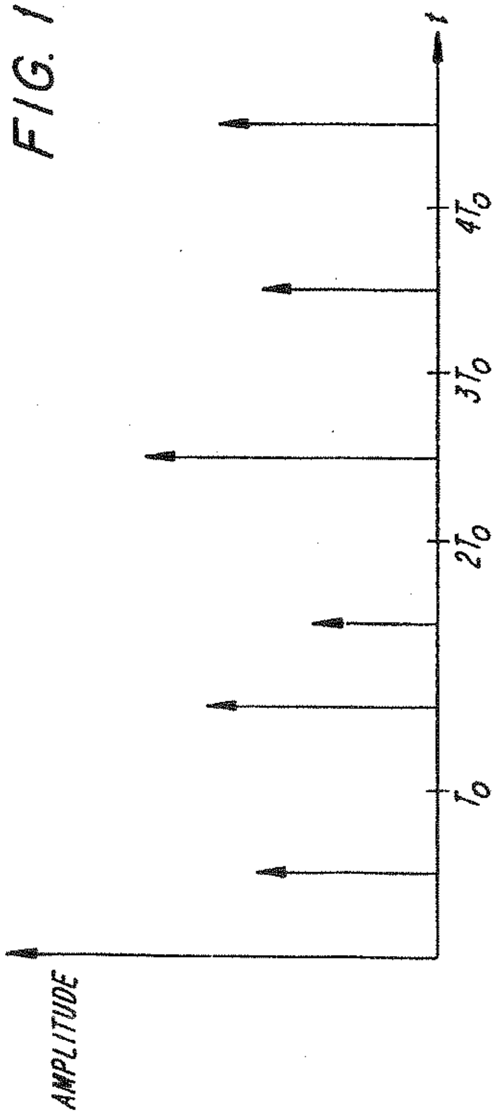
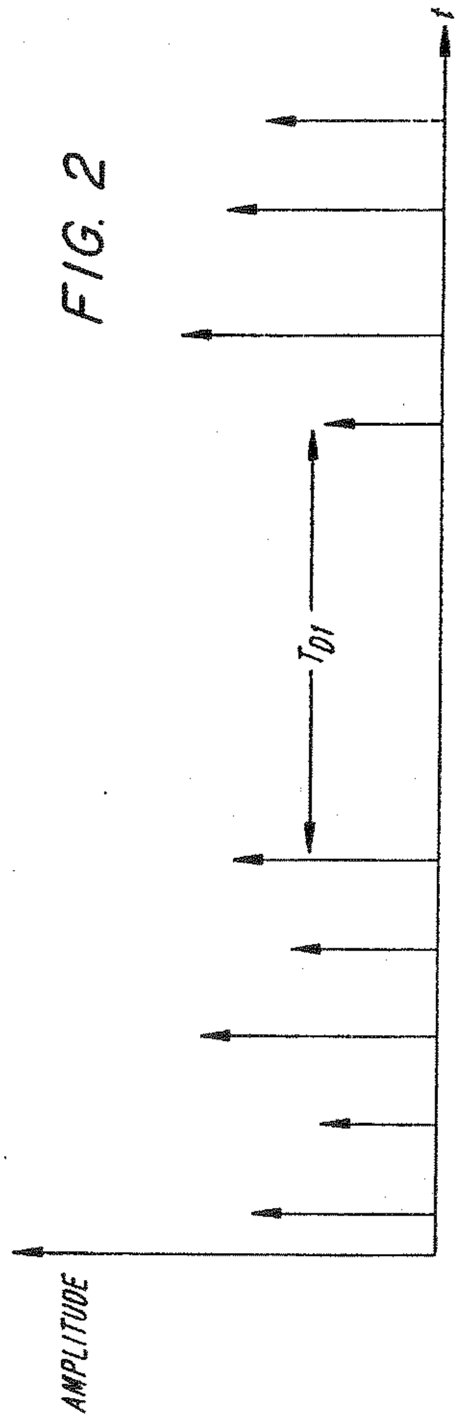
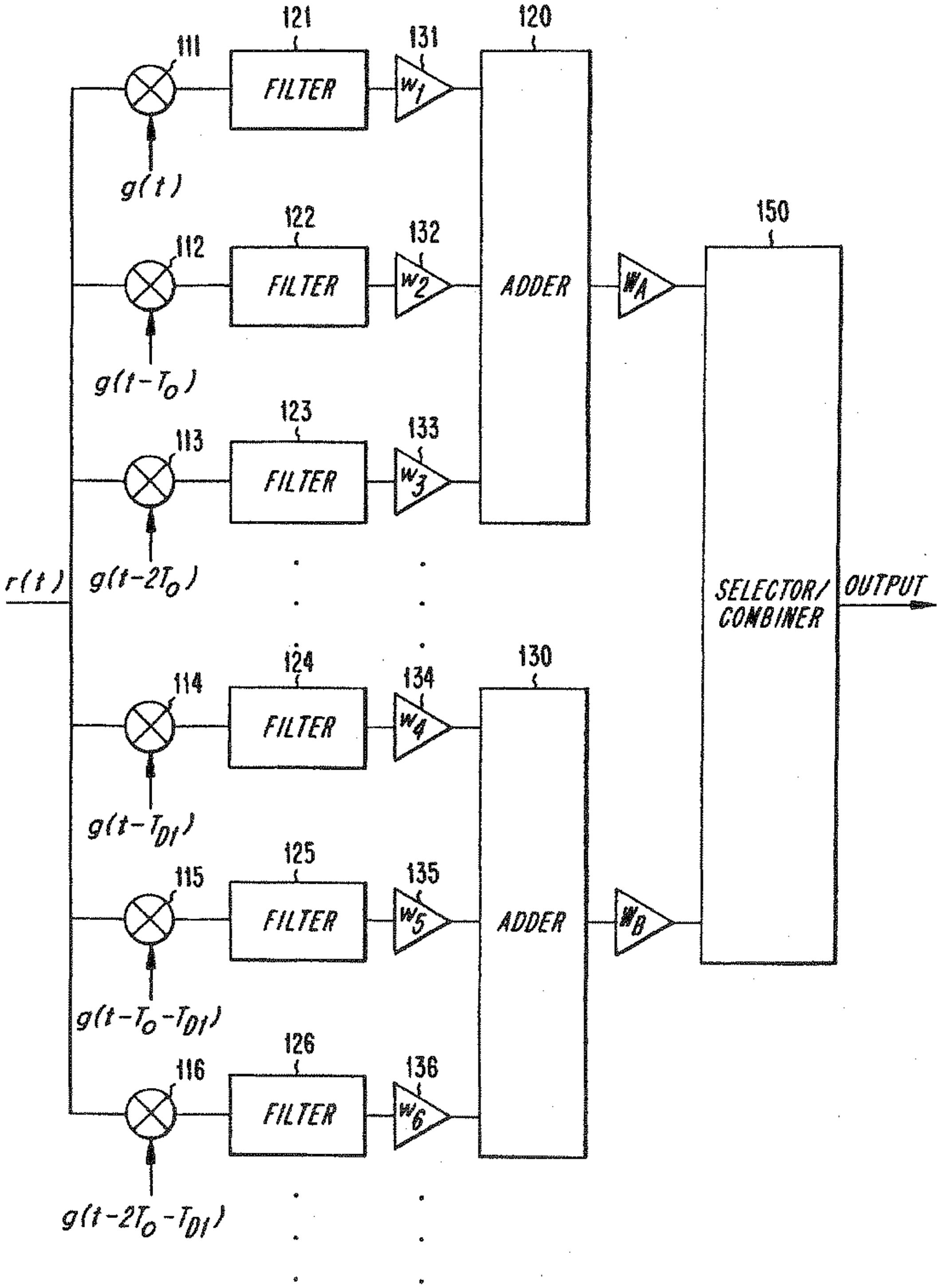


FIG. 2

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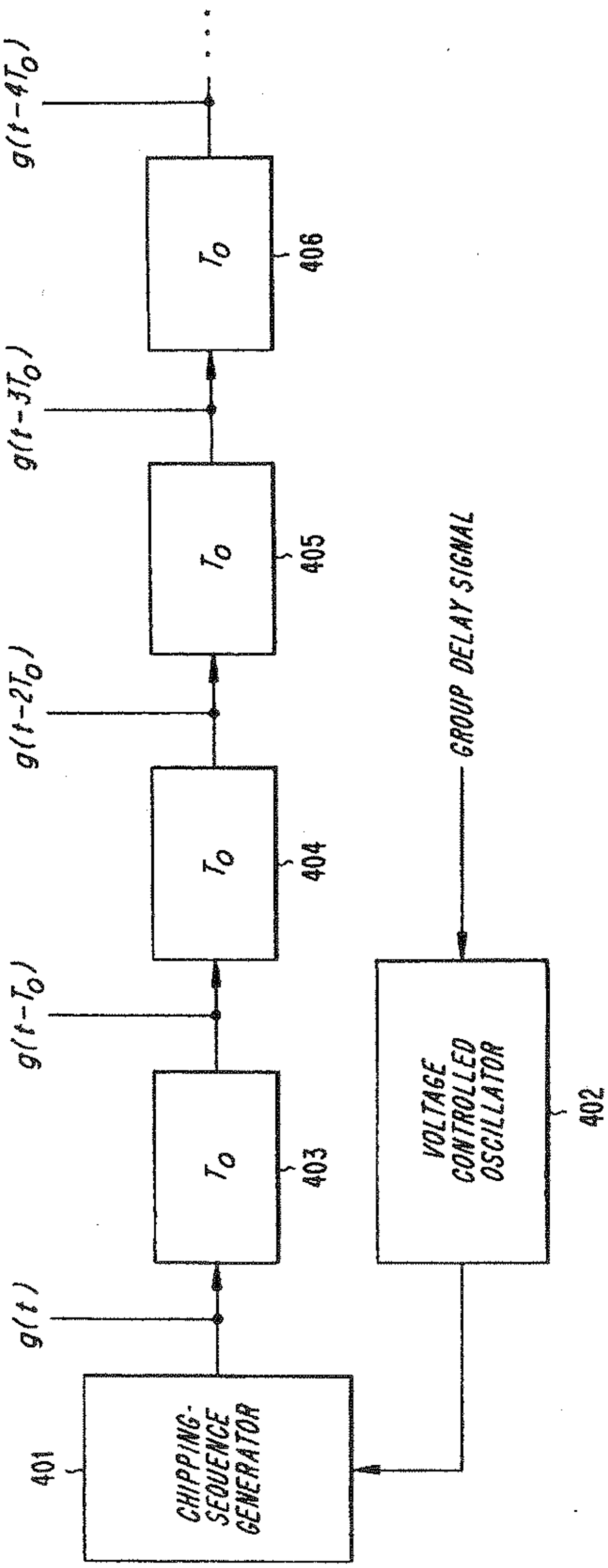
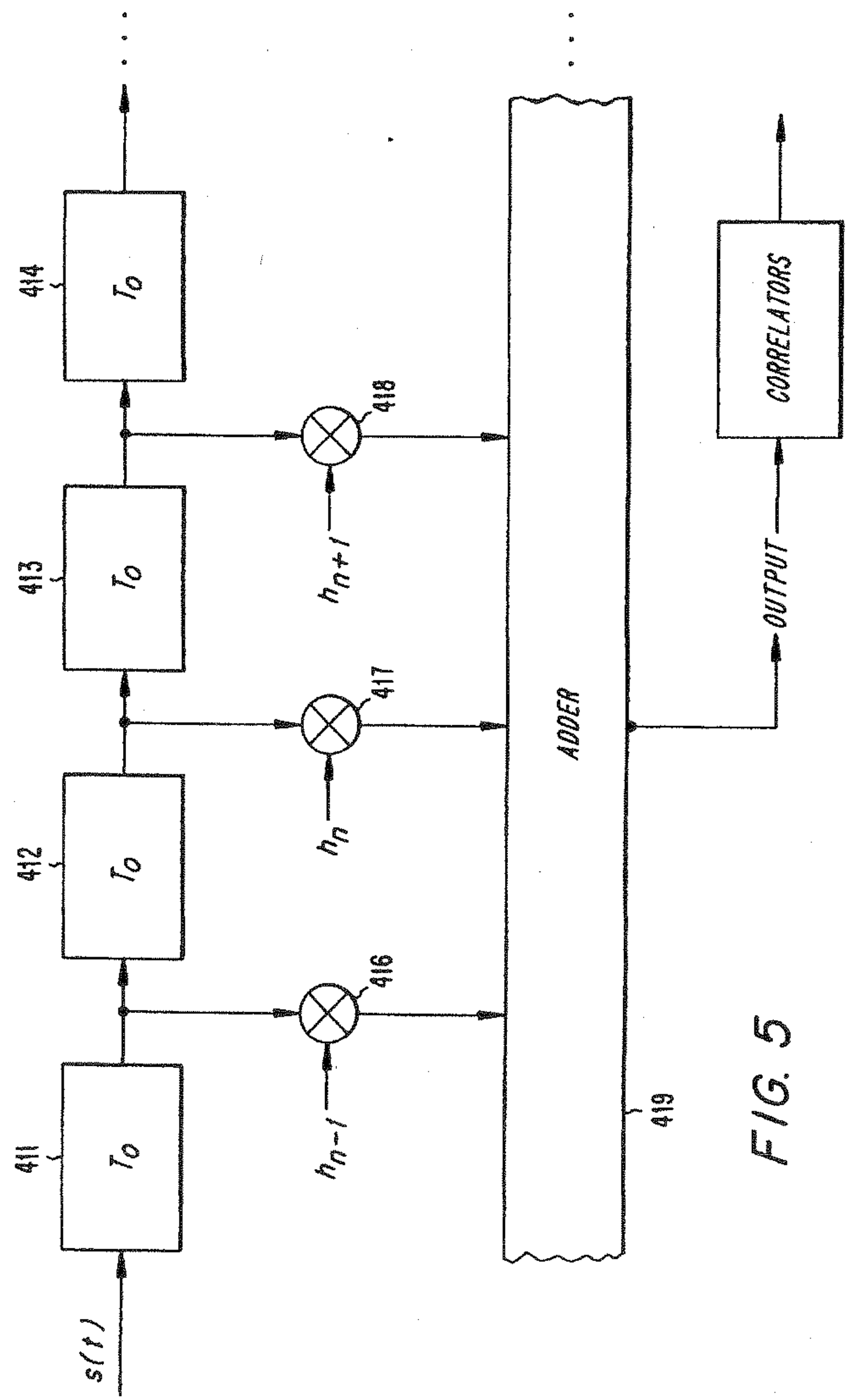
115
116
120
130
150
FILTER
FILTER
FILTER
FILTER
FILTER
FILTER
ADDER
ADDER
SELECTOR/
COMBINER
OUTPUT
r(t)
g(t)
g(t-T0)
g(t-2T0)
g(t-TD1)
g(t-T0-TD1)
g(t-2T0-TD1)
W1
W2
W3
W4
W5
W6
WA
WB

FIG. 3

FIG. 4



CHIPPING-SEQUENCE GENERATOR
401
VOLTAGE CONTROLLED OSCILLATOR
402
GROUP DELAY SIGNAL
g(t)
g(t−T_O)
g(t−2T_O)
g(t−3T_O)
g(t−4T_O)
T_O
403
404
405
406



411
412
413
414
T0
T0
T0
T0
416
417
418
s(t)
hn-1
hn
hn+1
ADDER
419
OUTPUT
CORRELATORS

FIG. 5

FIG. 6

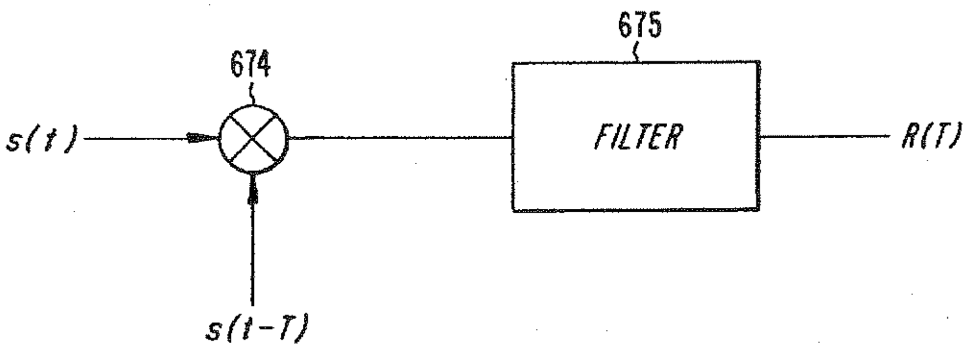


FIG. 7

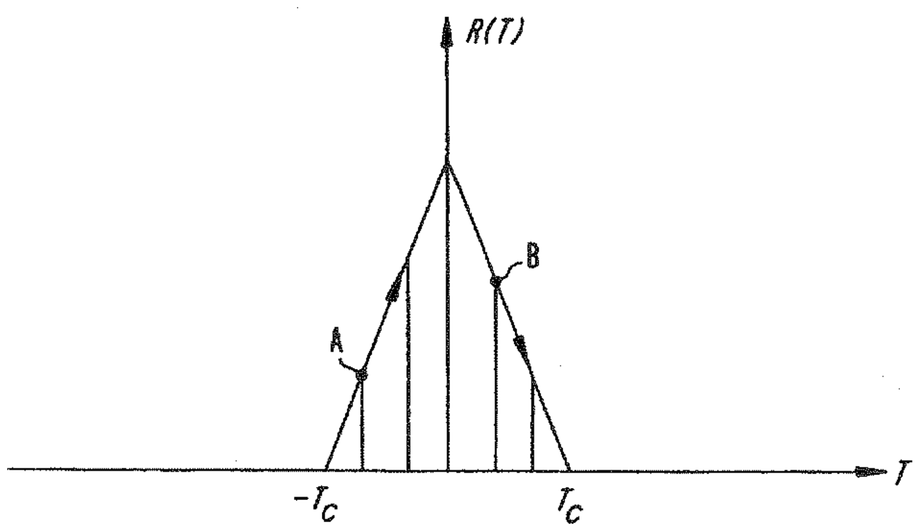
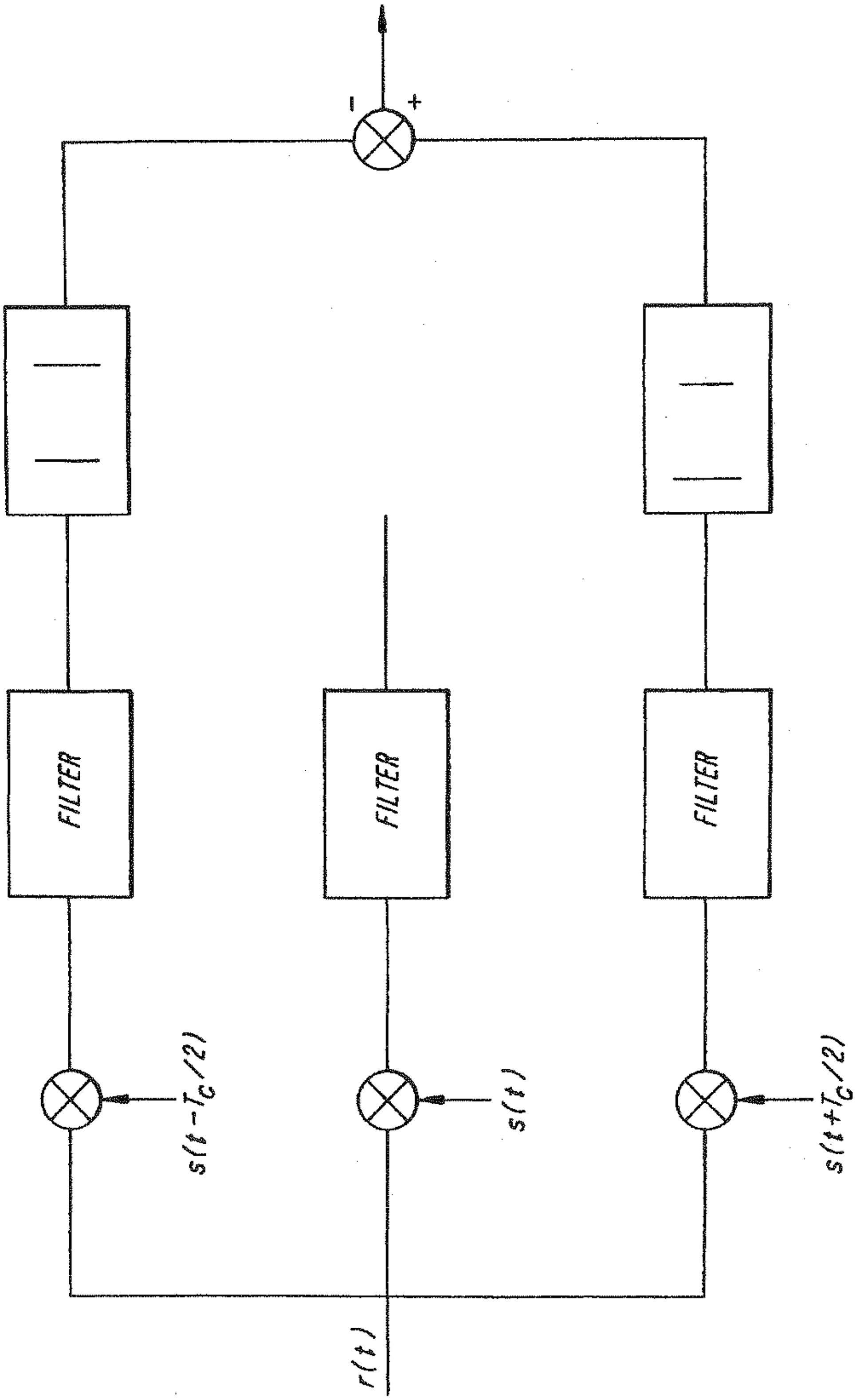
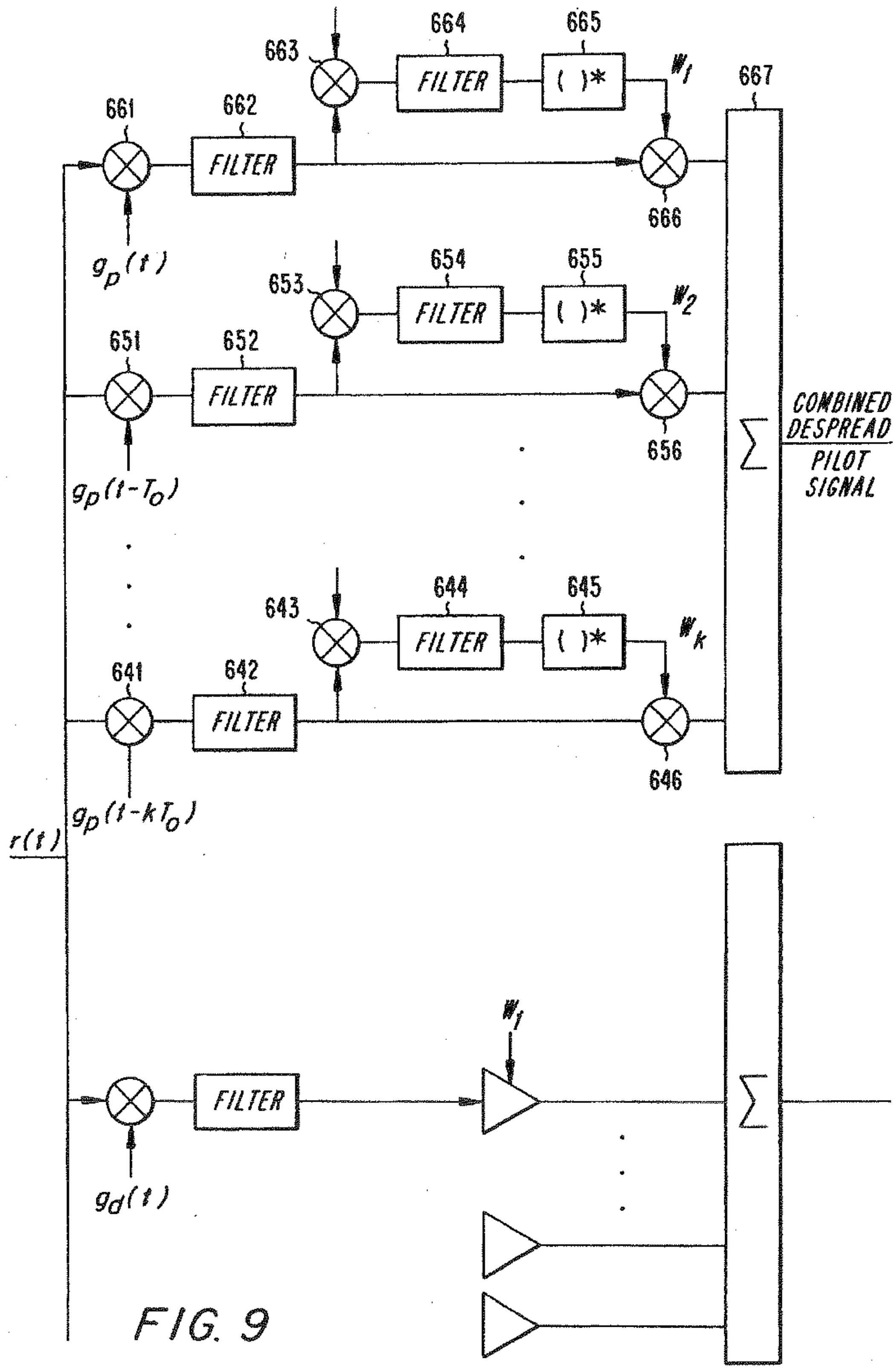


FIG. 8




663
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665
FILTER
( )*
W_1
667
661
662
FILTER
666
$g_p(t)$
653
654
655
FILTER
( )*
W_2
651
652
FILTER
656
COMBINED DESPREAD PILOT SIGNAL
$g_p(t-T_0)$
643
644
645
FILTER
( )*
W_k
641
642
FILTER
646
$g_p(t-kT_0)$
r(t)
W_1
FILTER
$g_d(t)$

FIG. 9

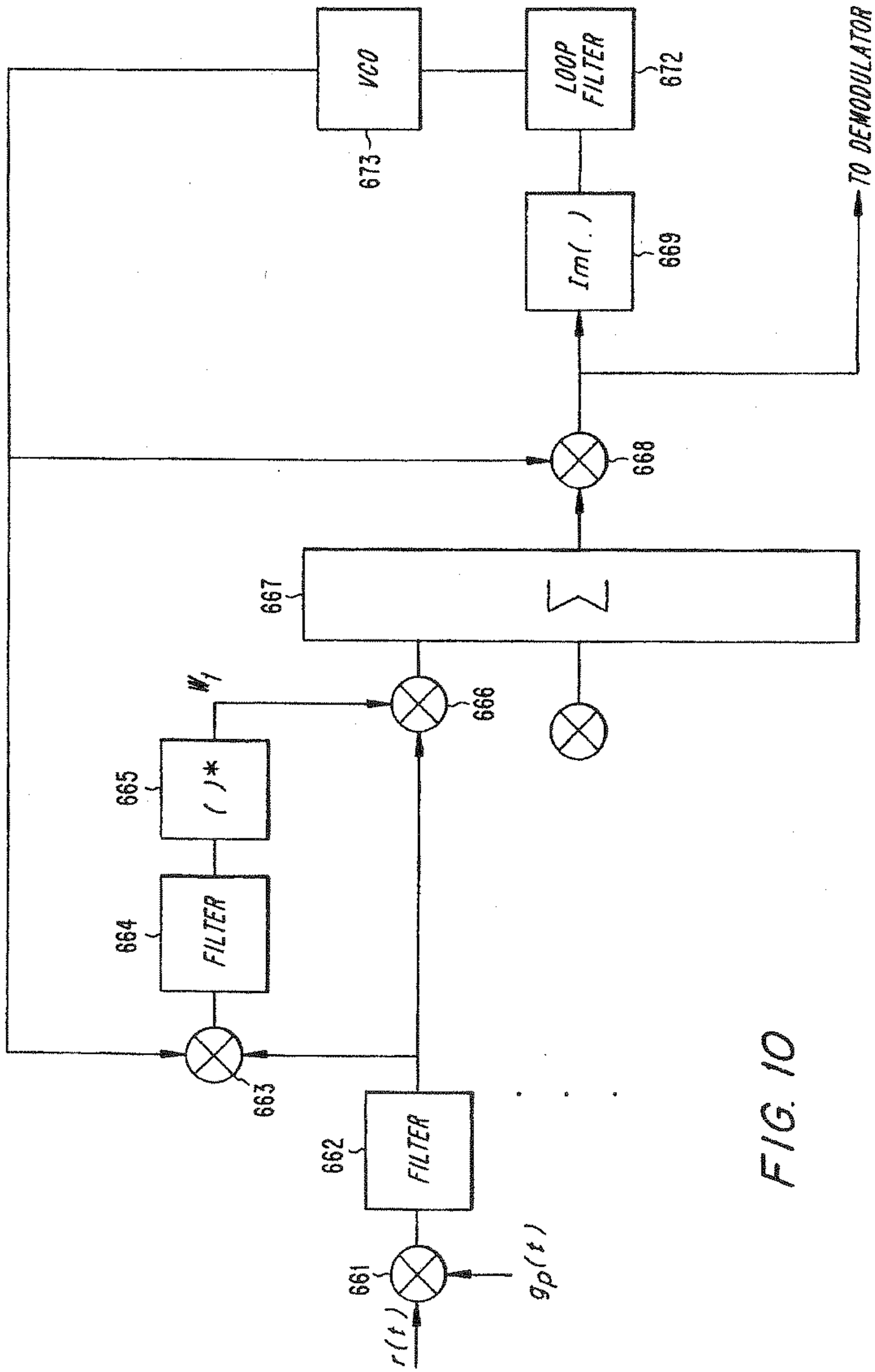

VCO
673
LOOP FILTER
672
TO DEMODULATOR
Im(.)
669
668
667
Σ
W1
666
665
( )*
664
FILTER
663
662
FILTER
661
r(t)
gp(t)

FIG. 10

FIG. 11

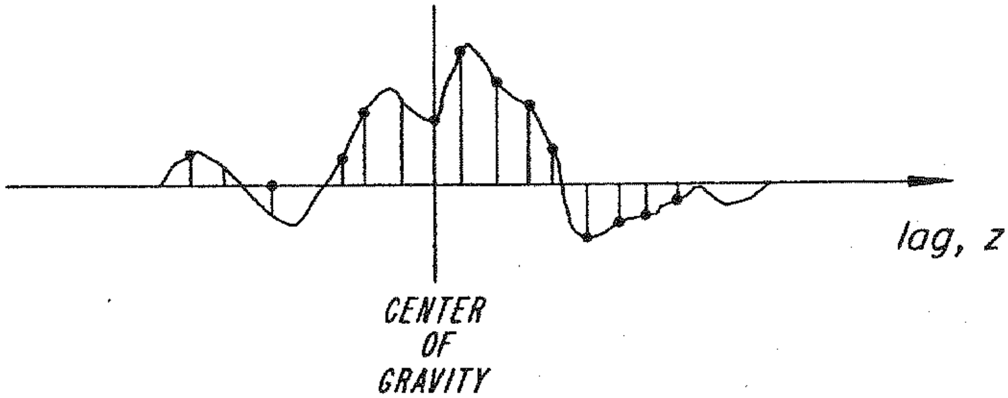


FIG. 12

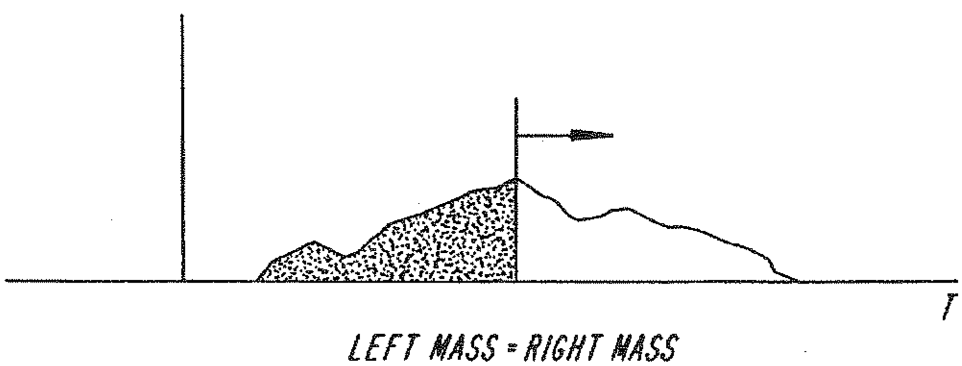
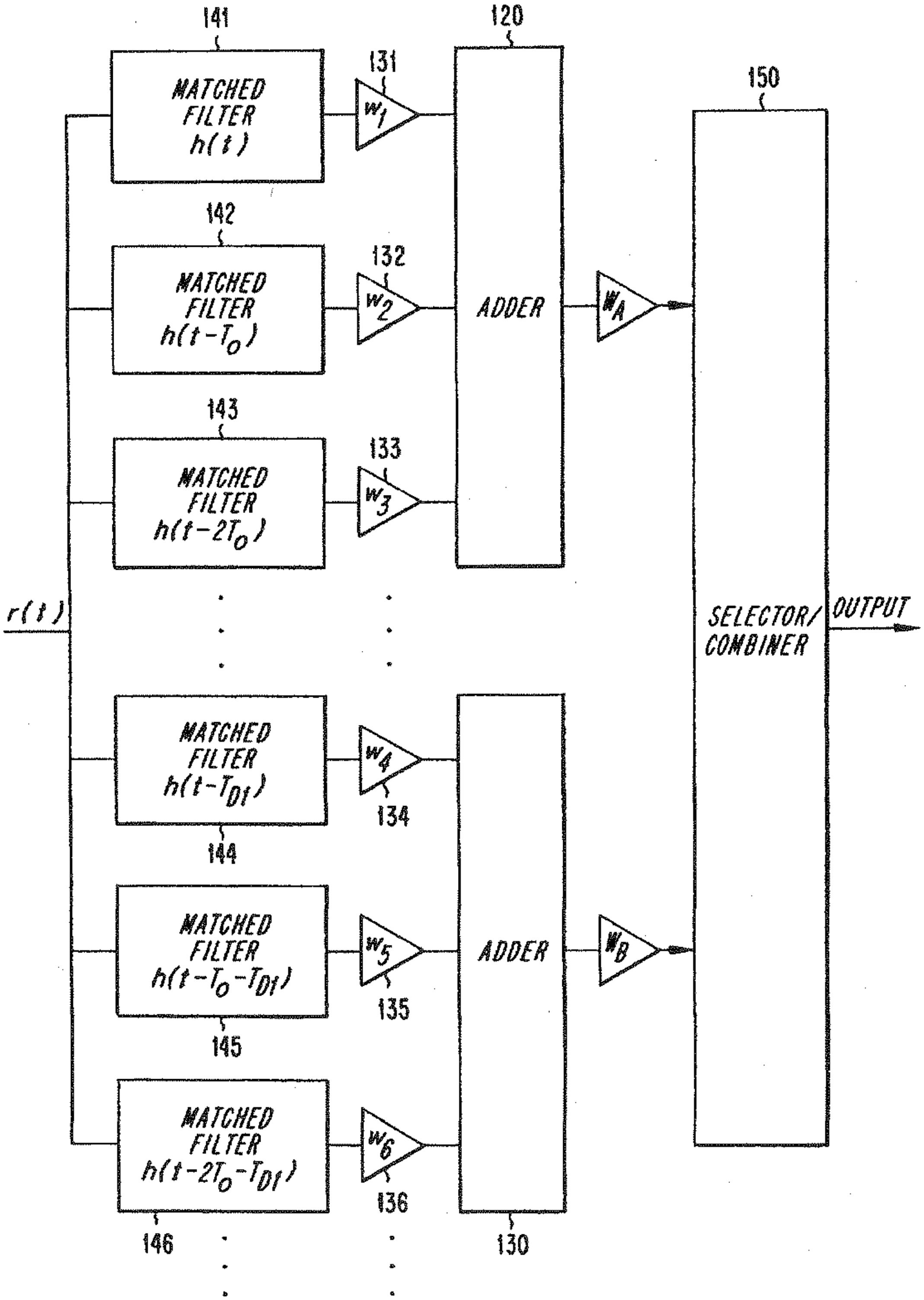
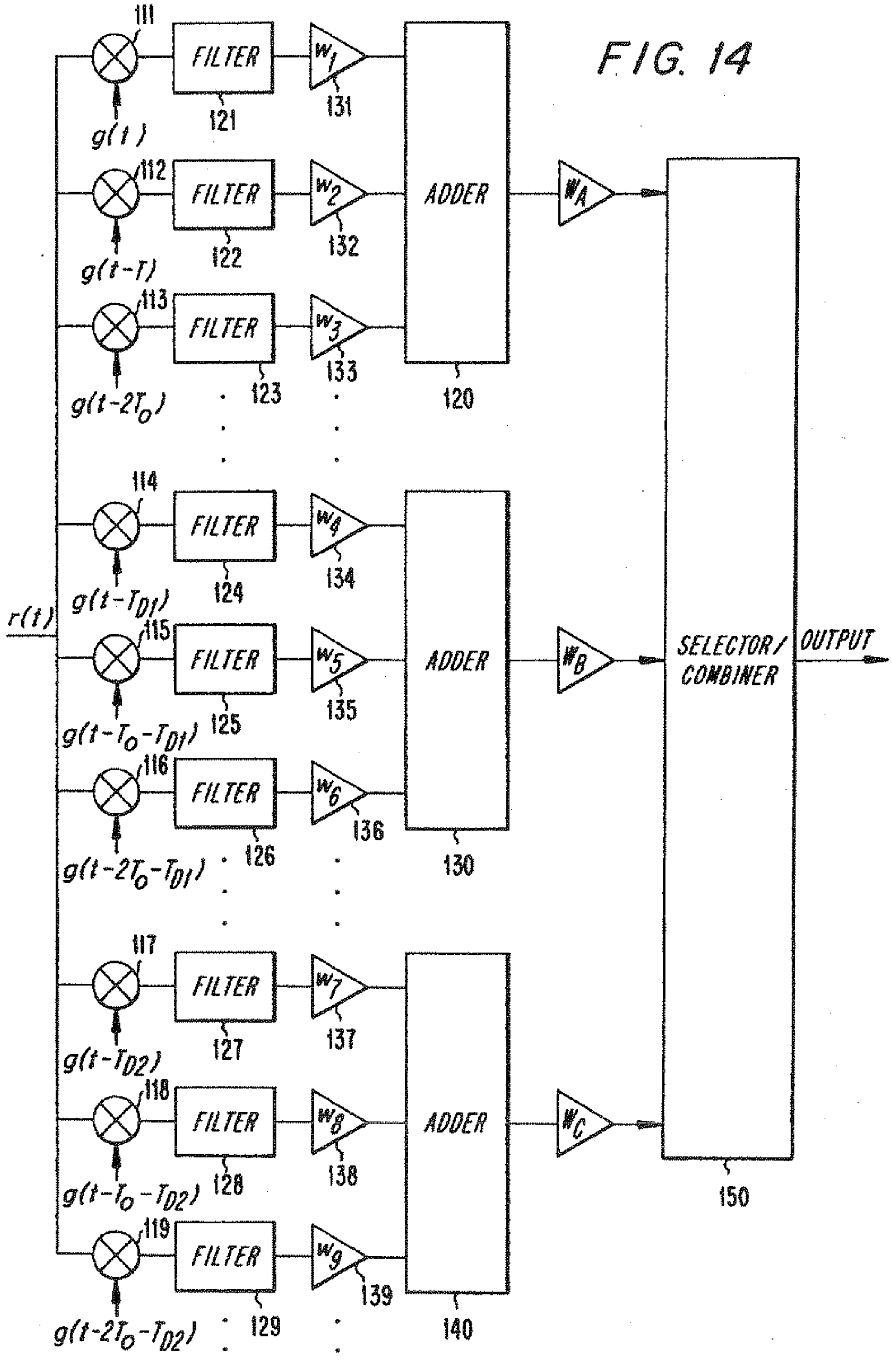


FIG. 13



141
120
131
150
MATCHED FILTER h(t)
w1
142
132
MATCHED FILTER h(t-T0)
w2
ADDER
WA
143
133
MATCHED FILTER h(t-2T0)
w3
r(t)
SELECTOR/ COMBINER
OUTPUT
MATCHED FILTER h(t-TD1)
w4
134
144
MATCHED FILTER h(t-T0-TD1)
w5
ADDER
WB
135
145
MATCHED FILTER h(t-2T0-TD1)
w6
136
146
130

FIG. 14



111
112
113
114
115
116
117
118
119
FILTER
121
122
123
124
125
126
127
128
129
131
132
133
134
135
136
137
138
139
ADDER
120
130
140
SELECTOR/ COMBINER
OUTPUT
150
r(t)
g(t)
g(t-T)
g(t-2T0)
g(t-TD1)
g(t-T0-TD1)
g(t-2T0-TD1)
g(t-TD2)
g(t-T0-TD2)
g(t-2T0-TD2)
W1
W2
W3
W4
W5
W6
W7
W8
W9
WA
WB
WC

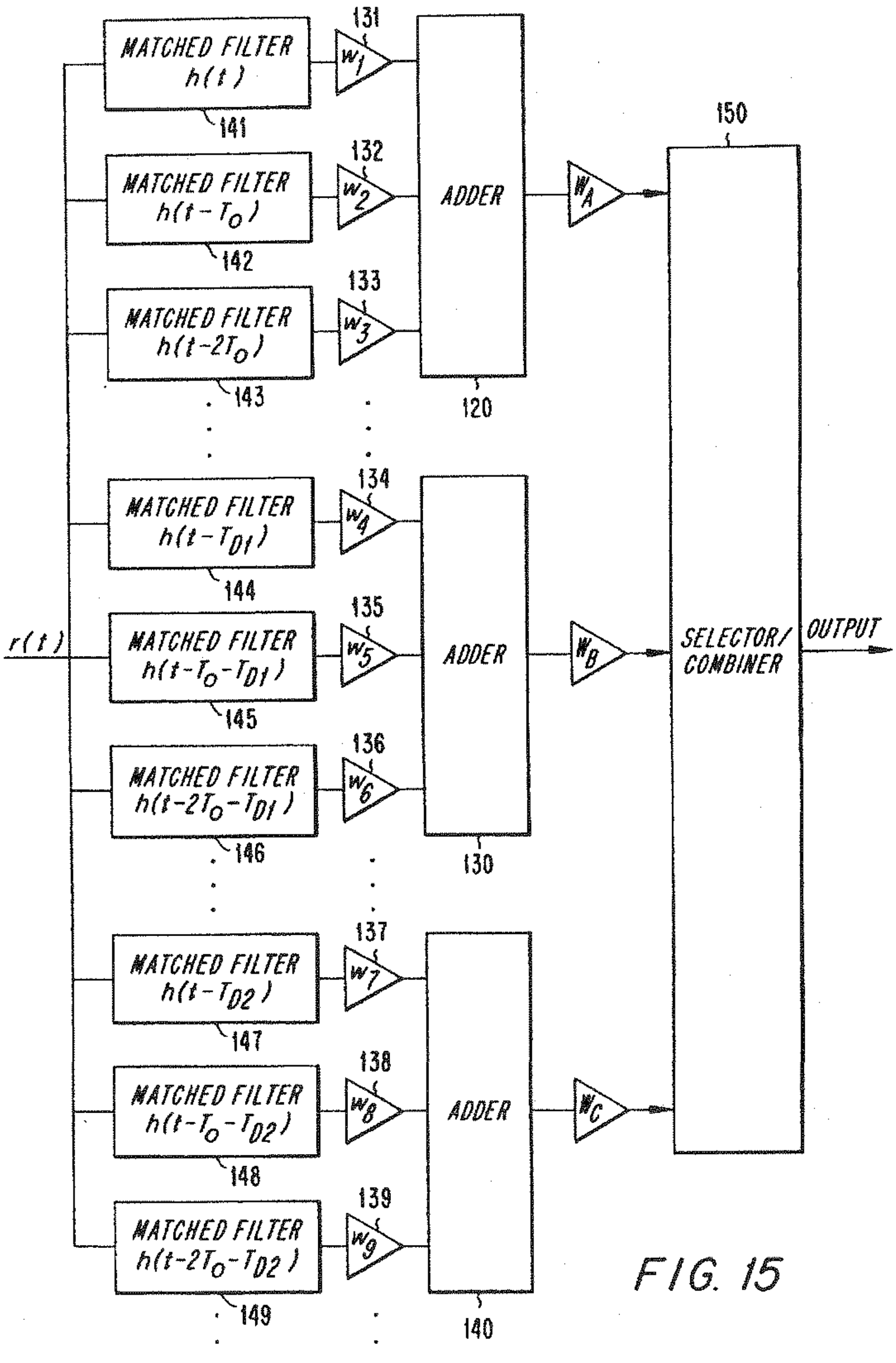

MATCHED FILTER h(t)
141
131
W1
MATCHED FILTER h(t−TO)
142
132
W2
MATCHED FILTER h(t−2TO)
143
133
W3
ADDER
120
WA
150
MATCHED FILTER h(t−TD1)
144
134
W4
MATCHED FILTER h(t−TO−TD1)
145
135
W5
MATCHED FILTER h(t−2TO−TD1)
146
136
W6
ADDER
130
WB
r(t)
SELECTOR/ COMBINER
OUTPUT
MATCHED FILTER h(t−TD2)
147
137
W7
MATCHED FILTER h(t−TO−TD2)
148
138
W8
MATCHED FILTER h(t−2TO−TD2)
149
139
W9
ADDER
140
WC

FIG. 15

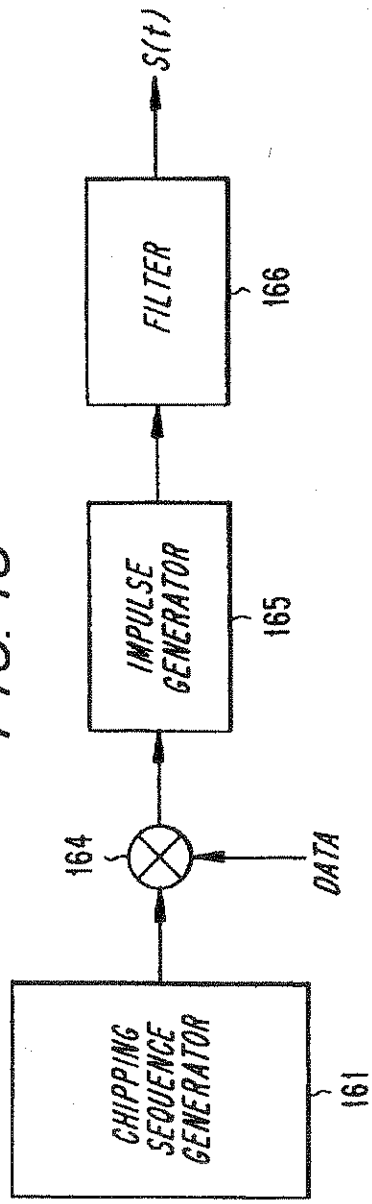

CHIPPING SEQUENCE GENERATOR
161
164
DATA
IMPULSE GENERATOR
165
FILTER
166
S(t)

FIG. 16

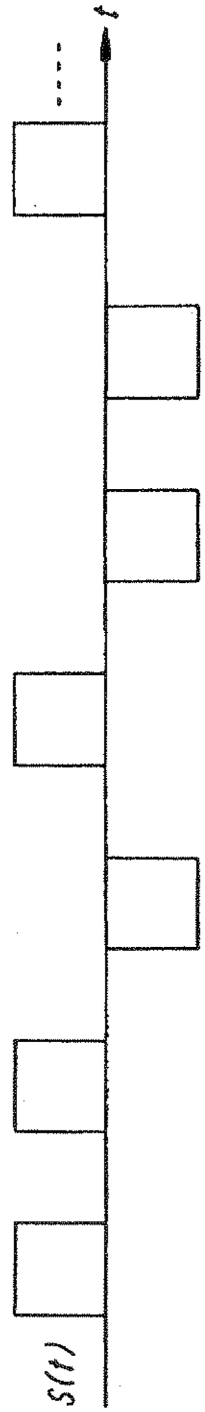

S(t)
t

FIG. 17

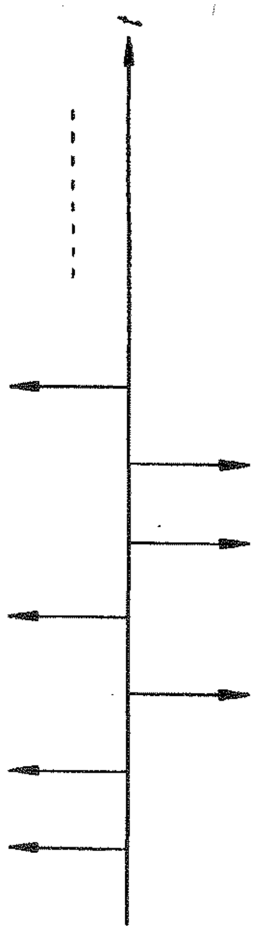

t

FIG. 18

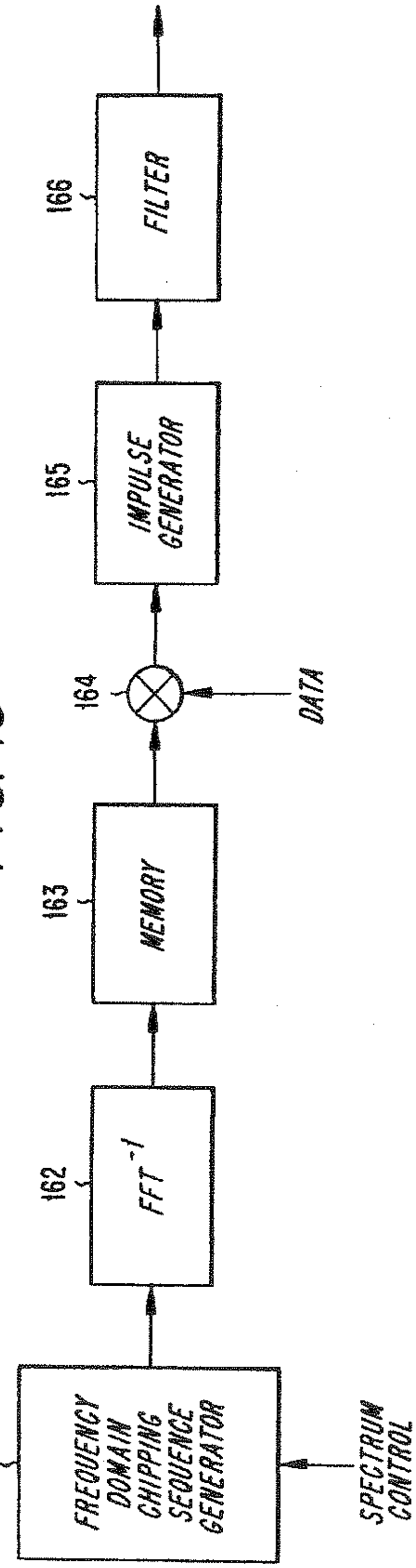

161
FREQUENCY DOMAIN CHIPPING SEQUENCE GENERATOR
SPECTRUM CONTROL
162
FFT^{-1}
163
MEMORY
164
DATA
165
IMPULSE GENERATOR
166
FILTER

FIG. 19

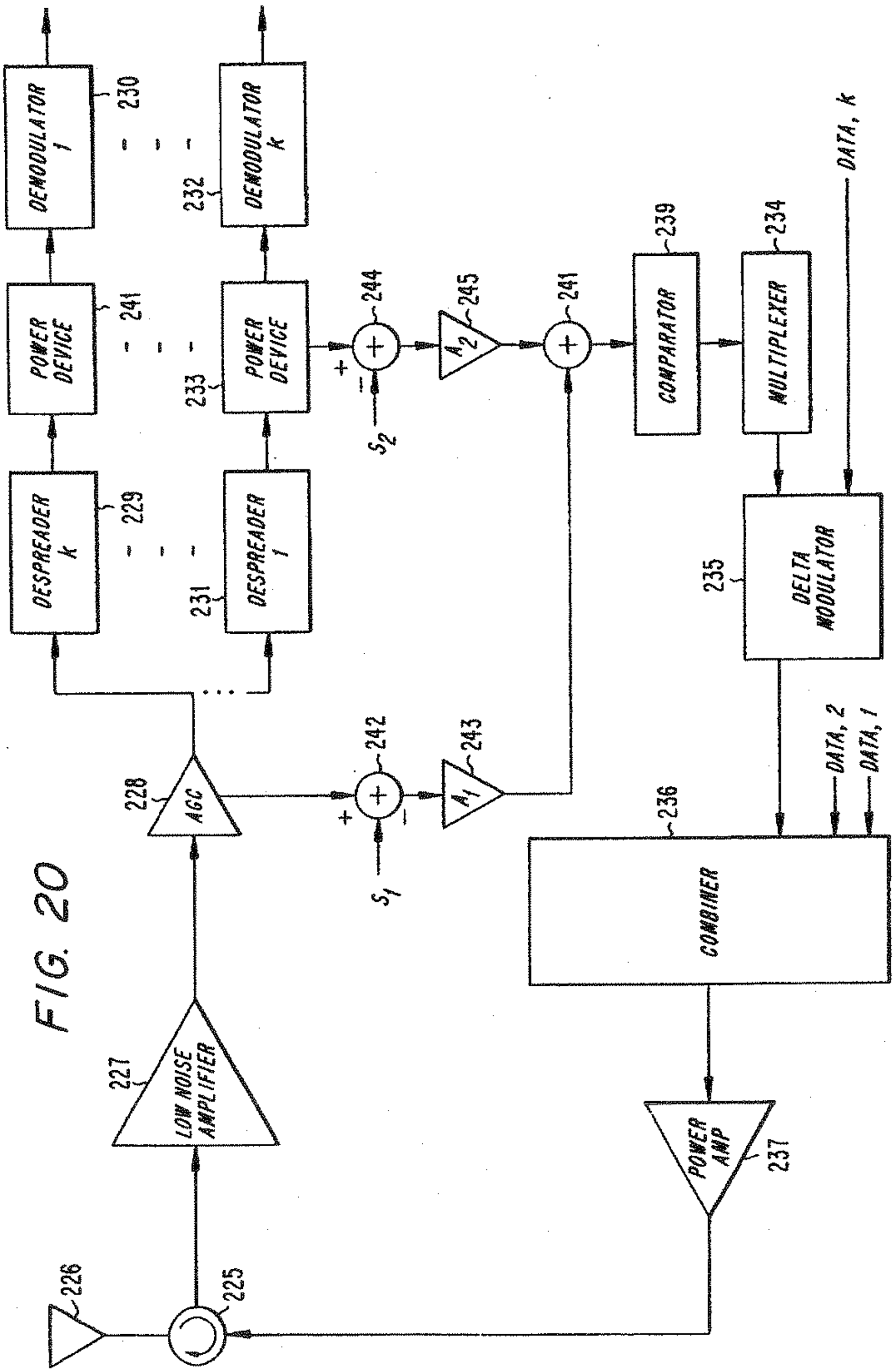

DEMODULATOR 1
230
DEMODULATOR k
232
POWER DEVICE
241
POWER DEVICE
233
DESPREADER k
229
DESPREADER 1
231
244
S_2
A_2
245
241
COMPARATOR
239
MULTIPLEXER
234
DATA, k
DELTA MODULATOR
235
AGC
228
242
S_1
A_1
243
COMBINER
236
DATA, 2
DATA, 1
LOW NOISE AMPLIFIER
227
POWER AMP
237
226
225

FIG. 20

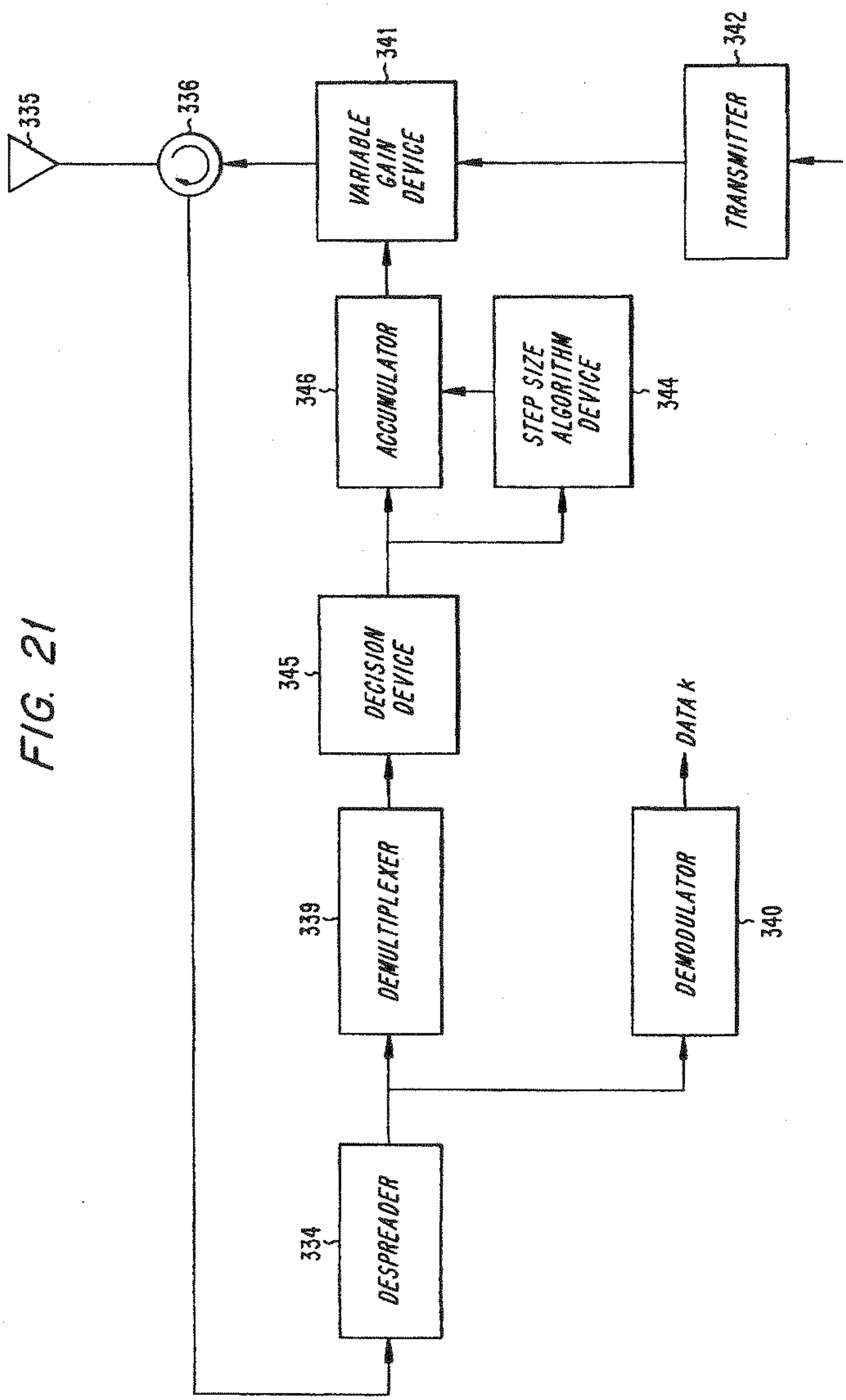

335
336
VARIABLE GAIN DEVICE
341
TRANSMITTER
342
ACCUMULATOR
346
STEP SIZE ALGORITHM DEVICE
344
DECISION DEVICE
345
DATA k
DEMULTIPLEXER
339
DEMODULATOR
340
DESPREADER
334

FIG. 21

FIG. 22

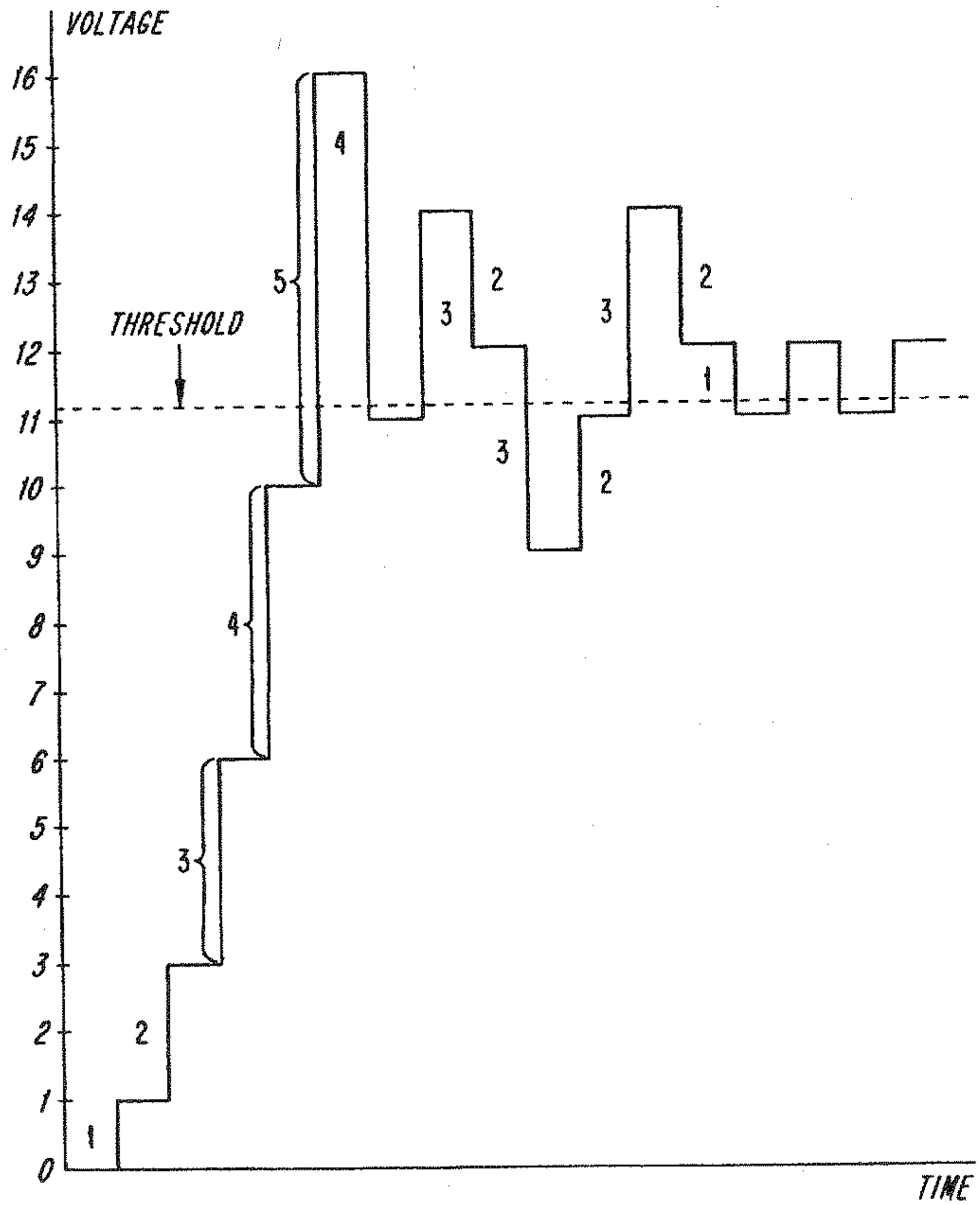
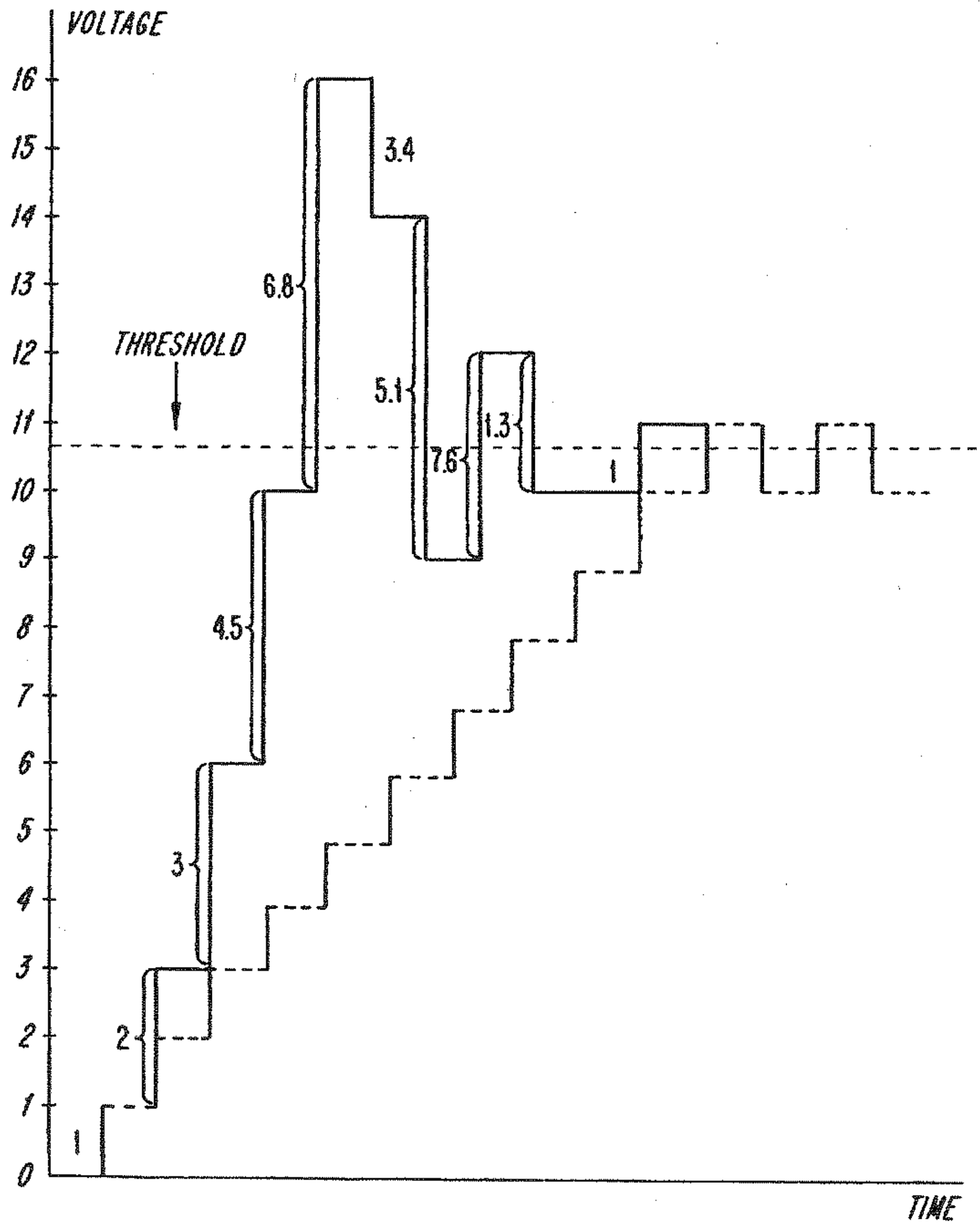
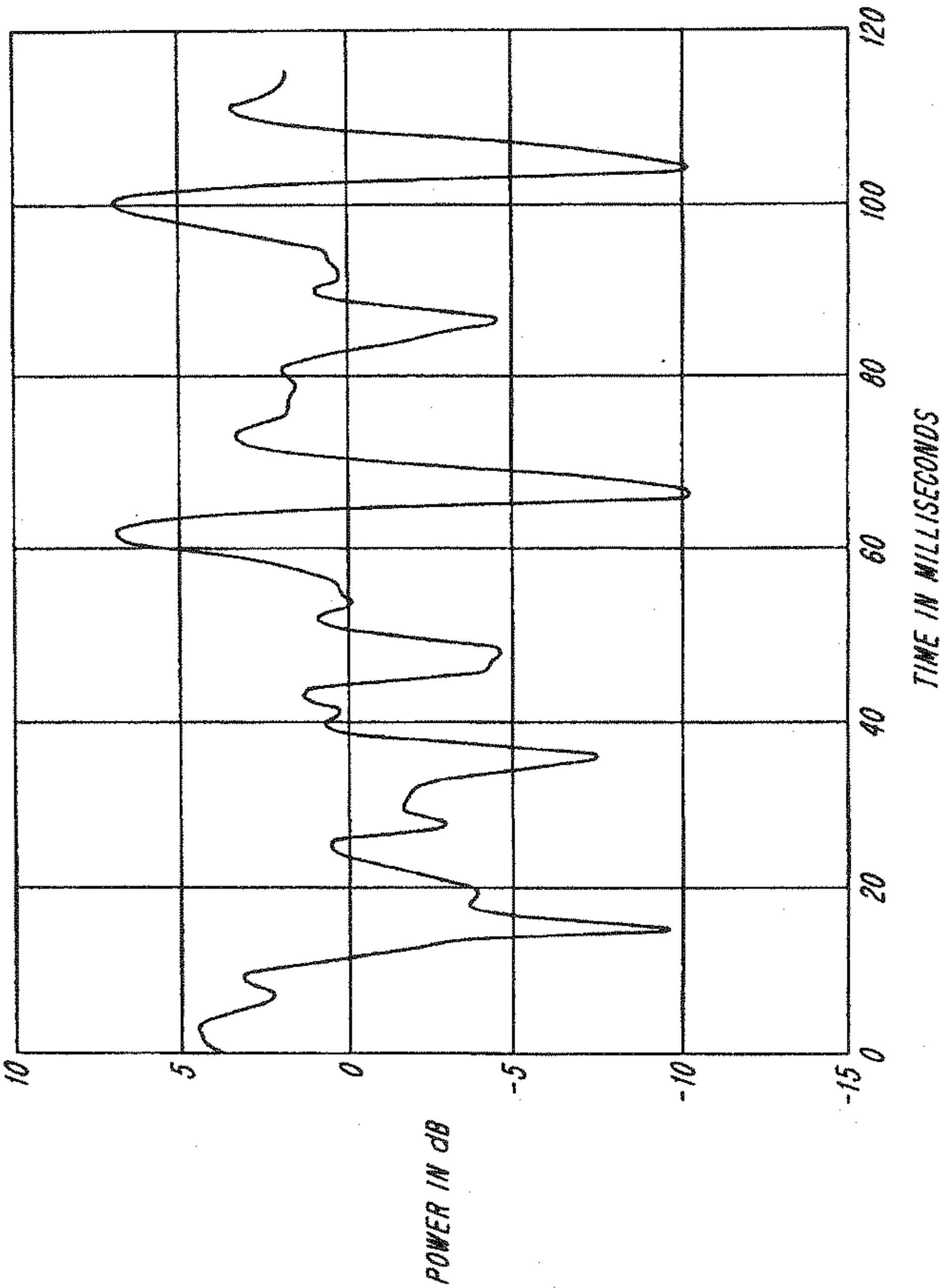

VOLTAGE
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
THRESHOLD
1
2
3
4
5
4
3
2
3
2
3
2
1
TIME

FIG. 23



VOLTAGE
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
THRESHOLD
6.8
3.4
5.1
7.6
1.3
1
4.5
3
2
1
TIME

FIG. 24



10
5
0
-5
-10
-15
POWER IN dB
0
20
40
60
80
100
120
TIME IN MILLISECONDS

FIG. 25

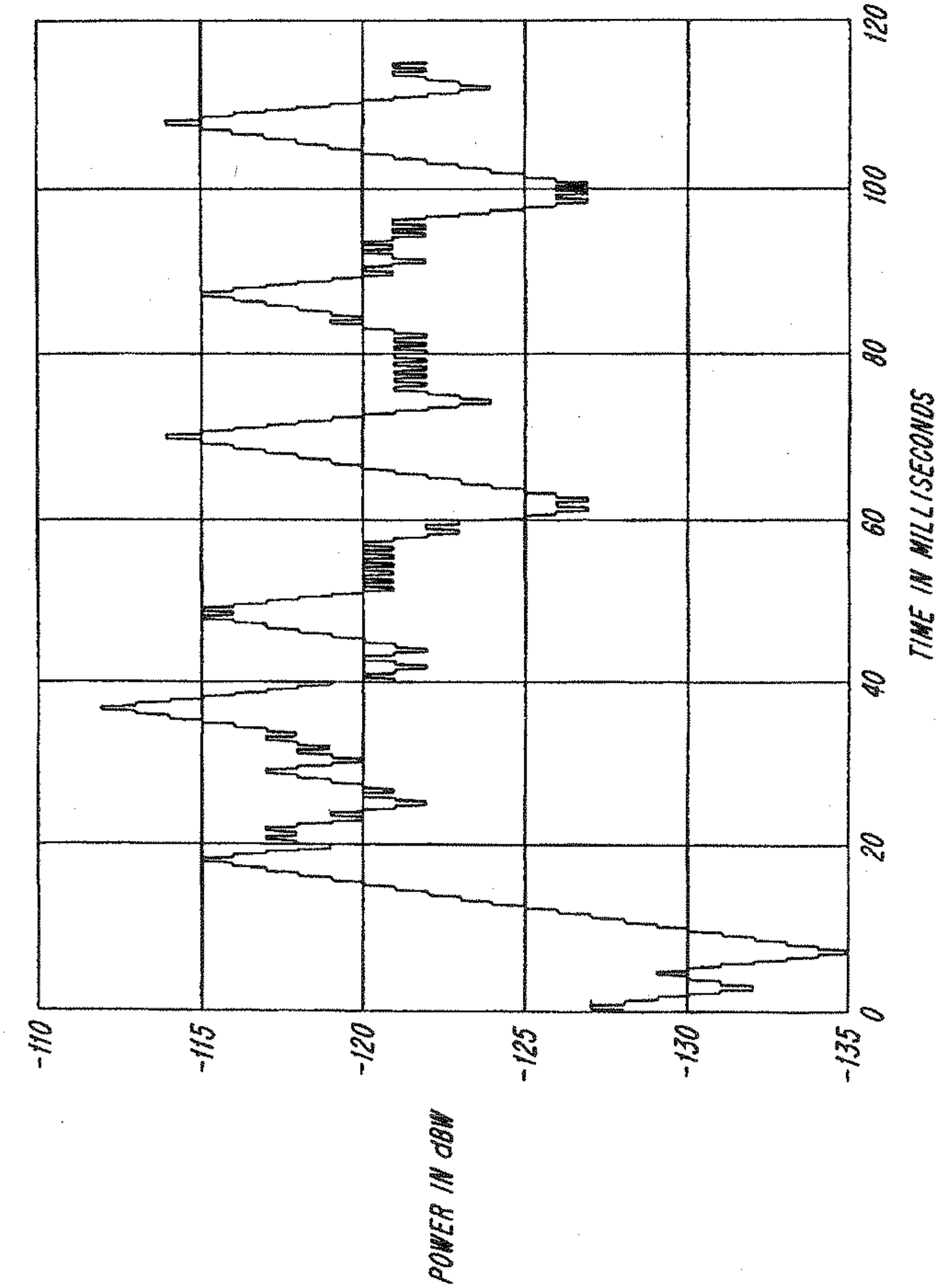

-110
-115
-120
-125
-130
-135
POWER IN dBW
0
20
40
60
80
100
120
TIME IN MILLISECONDS

FIG. 26

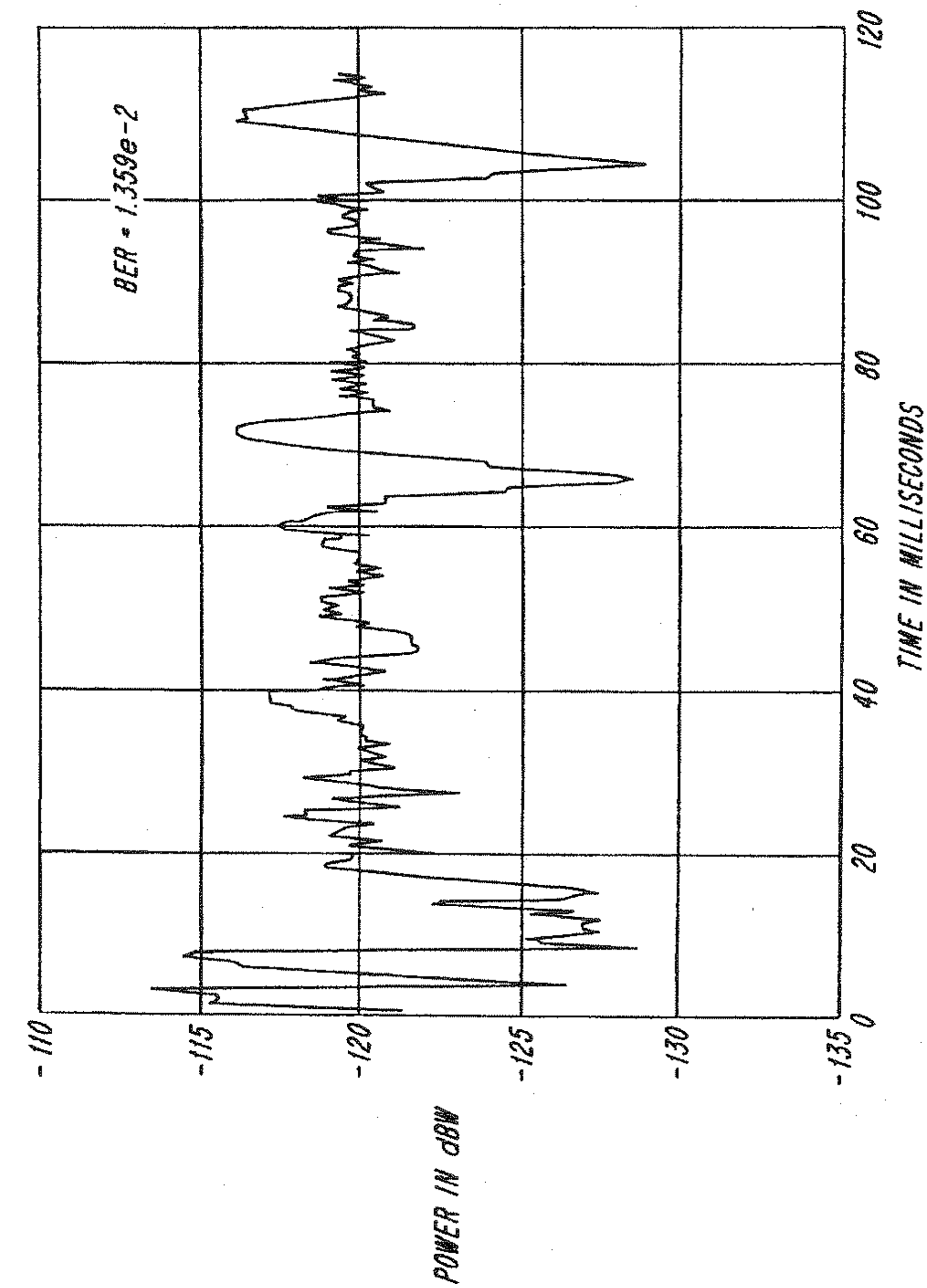

BER = 1.359e-2
0
20
40
60
80
100
120
TIME IN MILLISECONDS
-110
-115
-120
-125
-130
-135
POWER IN dBW

FIG. 27

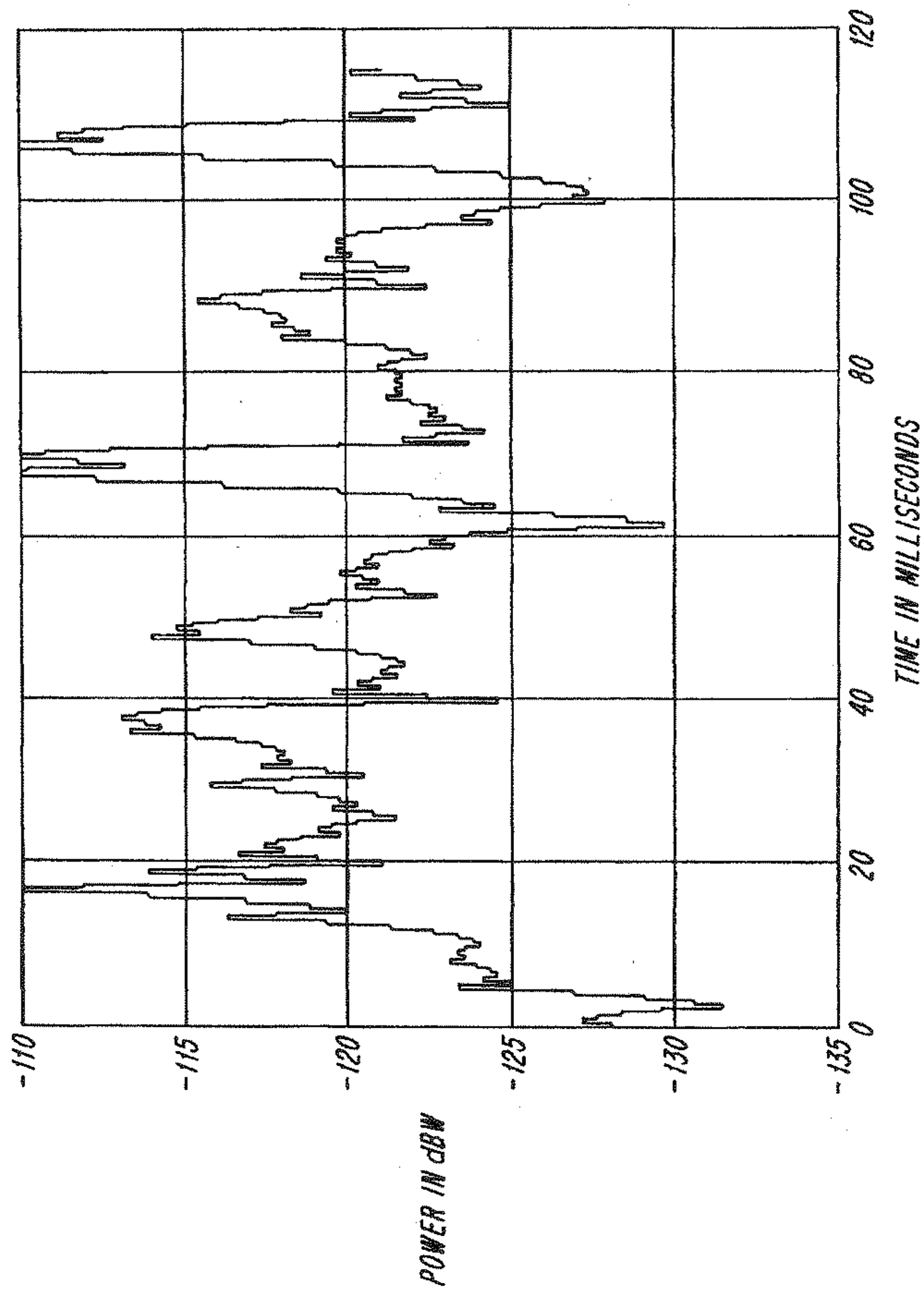
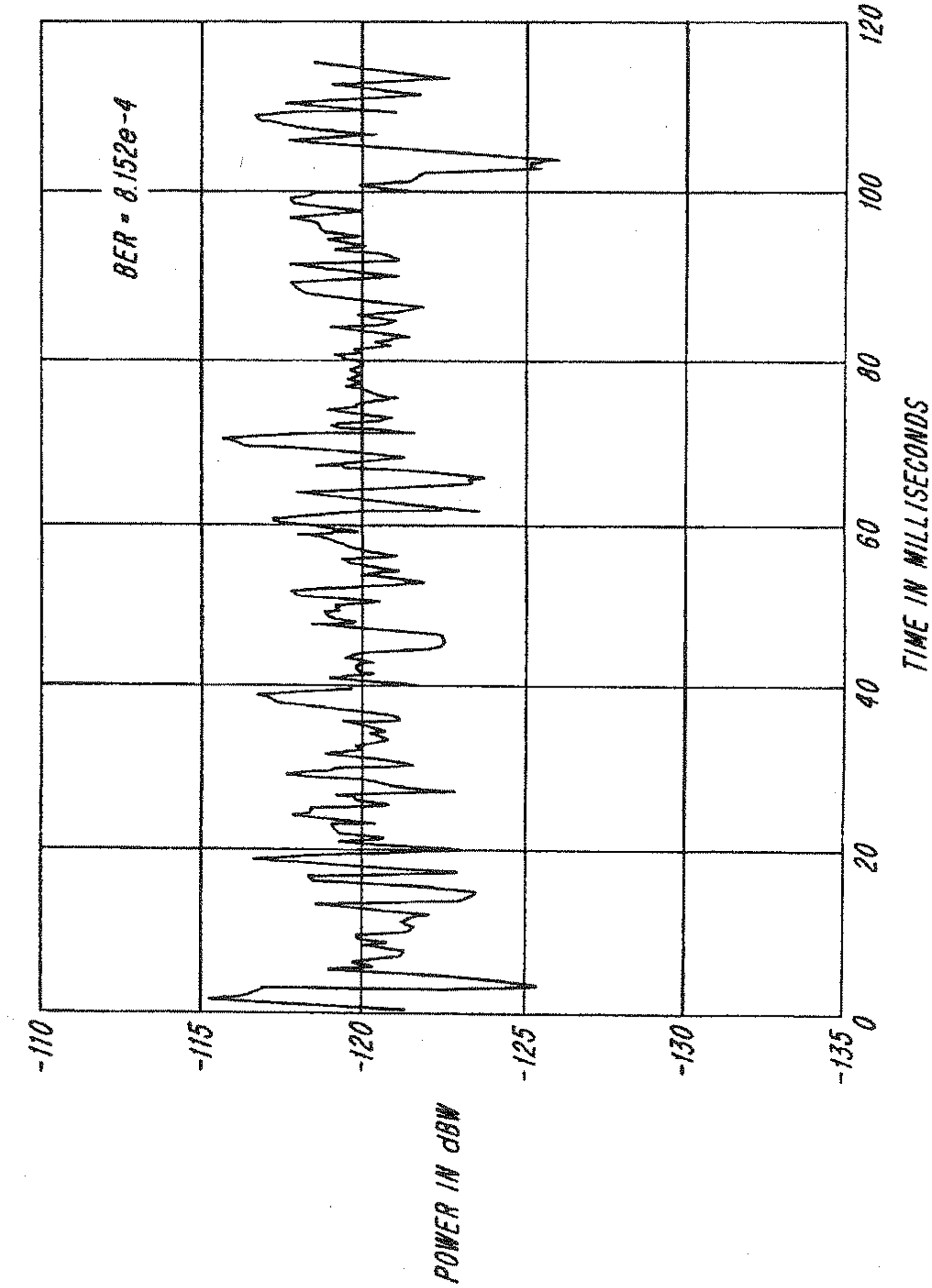

-110
-115
-120
-125
-130
-135
POWER IN dBW
0
20
40
60
80
100
120
TIME IN MILLISECONDS

FIG. 28


BER = 8.152e-4
-110
-115
-120
-125
-130
-135
POWER IN dBW
0
20
40
60
80
100
120
TIME IN MILLISECONDS

SPREAD SPECTRUM MULTIPATH PROCESSOR SYSTEM AND METHOD

This patent stems from a divisional of patent application entitled, SPREAD SPECTRUM SYSTEM AND METHOD, having Ser. No. 08/368,710, filing date Jan. 4, 1995. The benefit of the earlier filing date of the parent patent application is claimed pursuant to 35 U.S.C. § 120.

BACKGROUND OF THE INVENTION

This invention relates to spread-spectrum communications, and more particularly to a multipath processor, variable bandwidth device, and power control system.

DESCRIPTION OF THE RELEVANT ART

Spread-spectrum modulation provides means for communicating in which a spread-spectrum signal occupies a bandwidth in excess of the minimum bandwidth necessary to send the same information. The band spread is accomplished by modulating an information-data signal with a chipping-sequence signal which is independent of an information-data signal. The information-data signal may come from a data device such as a computer, or an analog device which outputs an analog signal which has been digitized to an information-data signal, such as voice or video. The chipping-sequence signal is generated by a chip-code where the time duration, T_c, of each chip is substantially less than a data bit or data symbol. A synchronized reception of the information-data signal with the chipping-sequence signal at a receiver is used for despreading the spread-spectrum signal and subsequent recovery of data from the spread-spectrum signal.

Spread-spectrum modulation offers many advantages as a communications system for an office or urban environment. These advantages include reducing intentional and unintentional interference, combating multipath problems, and providing multiple access to a communications system shared by multiple users. Commercially, these applications include, but are limited to, local area networks for computers and personal communications networks for telephone, as well as other data applications.

A cellular communications network, using spread-spectrum modulation for communicating between a base station and a multiplicity of users, requires control of the power level of a particular mobile user station. Within a particular cell, a mobile station near the base station of the cell may be required to transmit with a power level less than that required when the mobile station is near an outer perimeter of the cell. This adjustment in power level is done to ensure a constant power level is received at the base station from each mobile station.

In a first geographical region, such as an urban environment, the cellular architecture may have small cells in which the respective base stations are close to each other, requiring a low power level from each mobile user. In a second geographical region, such as a rural environment, the cellular architecture may have large cells in which the respective base stations are spread apart, requiring a relatively high power level from each mobile user. A mobile user who moves from the first geographical region to the second geographical region typically adjusts the power level of his transmitter in order meet the requirements of a particular geographic region. If such adjustments were not made, a mobile user traveling from a sparsely populated region with larger cells, using the relatively higher power level with his spread-spectrum transmitter, to a densely populated region with many small cells may, without reducing the original power level of his spread-spectrum transmitter, cause undesirable interference within the smaller cell into which he has traveled and/or to adjacent cells. Also, if a mobile user moves behind a building and has his signal to the base station blocked by the building, then the mobile user's power level should be increased. These adjustments must be made quickly, with high dynamic range and in a manner to ensure an almost constant received power level with low root mean square error and peak deviations from the constant level.

Accordingly, there is a need to have a spread-spectrum system and method for automatically controlling a mobile user's spread-spectrum transmitter power level when operating in a cellular communications network.

SUMMARY OF THE INVENTION

A general object of the invention is high capacity communications, due to lower multipath fading and total equivalent bandwidth and data rate.

A second general object of the invention is a spread spectrum transmitter having variable and/or adjustable signal bandwidth capabilities.

Another general object of the invention is a system and method which results in maximization of user density within a cell domain while minimizing mobile user transmitted power.

A further object of the invention is to provide an apparatus and method which controls the power level of a mobile station so that the power level received at the base station of each cell is the same for each mobile station.

Another object of the invention is to provide a system and method for automatically and adaptively controlling the power level of a mobile user in a cellular communications network.

A further object of the invention is to provide a spread-spectrum system and method which allows operating a spread-spectrum transmitter in different geographic regions, wherein each geographic region has a multiplicity of cells, and wherein cells within a geographic region may have different size cells and transmitter power requirements.

In a multipath environment, a spread spectrum signal reflects from multiple surfaces, such as buildings, and is assumed to generate a multiplicity of spread-spectrum signals. The multiplicity of spread-spectrum signals typically appear in a plurality of groups of spread-spectrum signals, with each group of spread-spectrum signals having a plurality of spread-spectrum signals. The plurality of groups of spread-spectrum signals are a result of the spread-spectrum signal reflecting in a multipath environment.

A multipath processor for tracking a spread-spectrum signal arriving in a plurality of groups is provided. The multipath processor includes a first plurality of correlators, a second plurality of correlators, a first adder, a second adder, and a selector device or a combiner device. The first adder is coupled between the first plurality of correlators and the selector device or the combiner device. The second adder is coupled between the second plurality of correlators and the selector device or the combiner device.

The first plurality of correlators despreads a first plurality of spread-spectrum signals within a first group to generate a first plurality of despread signals. The first adder adds or combines the first plurality of despread signals co generate a first combined-despread signal.

The second plurality of correlators despreads a second plurality of spread-spectrum signals within a second group to generate a second plurality of despread signals. The second adder adds or combines the second plurality of despread signals to generate a second combined-despread signal.

The selector device selects either the first combined-despread signal or the second combined-despread signal. The selected combined-despread signal is outputted from the decision device as an output-despread signal. Alternatively, the combiner device may combine or add the first combined-despread signal with the second combined-despread signal to generate the output-despread signal.

The present invention also includes a variable-bandwidth spread-spectrum device for use with a spread-spectrum transmitter. The variable-bandwidth spread-spectrum device generates a spread-spectrum signal having a spread bandwidth. The variable-bandwidth spread-spectrum device uses a chipping-sequence signal having a chipping rate, with the chipping rate being less than the spread bandwidth.

The variable-bandwidth spread-spectrum device includes a chipping-sequence generator, spread-spectrum processing means, an impulse generator, and a filter. The spread-spectrum processing means is coupled to the chipping-sequence generator. The impulse generator is coupled to the spread-spectrum processing means. The filter is coupled to the impulse generator.

The chipping-sequence generator generates the chipping-sequence signal with the chipping rate. The spread-spectrum processing means processes a data signal with the chipping-sequence signal to generate a spread-data signal. The impulse generator, responsive to each chip in the spread-data signal, generates an impulse signal. The filter filters a spectrum of each impulse signal with the spread bandwidth.

The spread-spectrum processing means may be embodied as an EXCLUSIVE-OR gate, a product device, or other device as is well known in the art for spread-spectrum processing data signals with chipping-sequence signals. The filter may include a variable bandwidth filter. The variable bandwidth filter may be used for varying or adjusting the spread bandwidth of the spectrum for each impulse signal. Accordingly, a spread-spectrum signal may be designed having the bandwidth of choice, based on the bandwidth of the variable-bandwidth filter. The bandwidth my be variable, or adjustable, as would be required for particular system requirements. As used in this patent, a variable bandwidth is one that is able to vary according to time conditions or other requirements in a particular system. An adjustable bandwidth would be similar to a variable bandwidth, but is used to refer to a bandwidth which may be adjusted to remain at a chosen setting.

A system for adaptive-power control (APC) of a spread-spectrum transmitter is also provided. A plurality of mobile stations operate in a cellular-communications network using spread-spectrum modulation. A mobile station transmits a first spread-spectrum signal. The base station transmits a second spread-spectrum signal.

The base station includes automatic gain control (AGC) means, base-correlator means, comparator means, power means, transmitter means, and an antenna. The base-correlator means is coupled to the AGC means. The power means is coupled to the base-correlator means and to the comparator means. The comparator means is coupled to the power means. The antenna is coupled to the transmitter means.

Each mobile station includes despreading means and variable-gain means.

A received signal is defined herein to include the first spread-spectrum signal and an interfering signal. The interfering signal is defined herein to include noise and/or other spread-spectrum signals and/or other undesirable signals which are coexistent in frequency with the first spread-spectrum signal.

For each received signal, the AGC means generates an AGC-output signal. The base-correlator means despreads the AGC-output signal. The power means processes the despread-AGC-output signal and generates a received-power level. The comparator means generates a power-command signal by comparing the received-power level to a threshold level. The power-command signal may be an analog or digital data signal, or a data signal multiplexed with information data bits. The transmitter means at the base station transmits the power-command signal as the second spread-spectrum signal or as a data signal multiplexed with the information data bits.

At each mobile station, the despreading means despreads the power-color, end signal from the second spread-spectrum signal as a power-adjust signal. The variable-gain means uses the power-adjust signal as a basis for adjusting a transmitter-power level of the first spread-spectrum signal transmitted from the mobile-station transmitter. The transmitter-power level may be adjusted linearly or nonlinearly.

The present invention also includes a method for automatic-power control of a spread-spectrum transmitter for a mobile station operating in a cellular-communications network using spread-spectrum modulation. A mobile station transmits a first spread-spectrum signal. The base station performs the steps of acquiring the first spread-spectrum signal transmitted from the mobile station, and detecting a received power level of the first spread-spectrum signal plus any interfering signal including noise. The steps also include generating an AGC-output signal from the received signal, and despreading the AGC-output signal. The despread AGC-output signal is processed to generate a received-power level. The method further includes comparing the received-power level to the threshold level to generate a power-command signal. The power-command signal is transmitted from the base station as part of the second spread-spectrum signal.

An the mobile station the method despreads the power-command signal from the second spread-spectrum signal, and adjusts a transmitter power level of the first spread-spectrum signal in response to the power-command signal.

Additional objects and advantages of the invention are set forth in part in the description which follows, and in part are obvious from the description, or may be learned by practice of the invention. The objects and advantages of the invention also may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate preferred embodiments of the invention, and together with the description serve to explain the principles of the invention.

FIG. 1 illustrates channel impulse response giving rise to several multipath signals;

FIG. 2 illustrates conditions leading to two groups of several multipath signals;

FIG. 3 is a block diagram of a multipath processor using two sets of correlators for despreading a spread-spectrum signal received as two groups of spread-spectrum signals;

FIG. 4 is a block diagram for generating chipping-sequence signals with delays;

FIG. 5 is a tapped-delay line model of a communications channel;

FIG. 6 is a block diagram of a correlator;

FIG. 7 is-an auto correlation function diagram generated from the correlator of FIG. 6;

FIG. 8 is a block diagram for tracking a received signal;

FIG. 9 is a block diagram for combining a pilot signal from a received spread-spectrum signal;

FIG. 10 is a block diagram for tracking a pilot signal embedded in a pilot channel of a spread-spectrum signal;

FIG. 11 illustrates cross-correlation between a received signal and a referenced chipping-sequence signal, as a function of referenced delay;

FIG. 12 illustrates the center of gravity of the cross-correlation function of FIG. 11;

FIG. 13 is a block diagram of a multipath processor using two sets of matched filters for despreading a spread-spectrum signal received as two groups of spread-spectrum signals;

FIG. 14 is a block diagram of a multipath processor using three sets of correlators for despreading a spread-spectrum signal received as three groups of spread-spectrum signals;

FIG. 15 is a block diagram of a multipath processor using three matched filters for despreading a spread-spectrum signal received as three groups of spread-spectrum signals;

FIG. 16 is a block diagram of a variable-bandwidth spread-spectrum device;

FIG. 17 illustrates chips of a spread-data signal;

FIG. 18 illustrates impulse signals corresponding to the chips of the spread-data signal of FIG. 17;

FIG. 19 is an alternative block diagram of the variable-bandwidth spread-spectrum-device of FIG. 16;

FIG. 20 is a block diagram of a base station;

FIG. 21 is a block diagram of a mobile station;

FIG. 22 illustrates nonlinear power adjustment;

FIG. 23 illustrates linear and nonlinear power adjustment;

FIG. 24 illustrates fades during transmission for multiple signals of equivalent power received at a base station;

FIG. 25 illustrates an adaptive power control signal of broadcast power for a fixed step algorithm;

FIG. 26 illustrates despread output power for a fixed step algorithm;

FIG. 27 illustrates an adaptive power control signal of broadcast power for a variable step algorithm; and

FIG. 28 illustrates despread output power for a variable step algorithm.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference now is made in detail to the present preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings, wherein like reference numerals indicate like elements throughout the several views.

Multipath Processor

In a multipath environment, a signal reflects from several buildings or other structures. The multiple reflections from the several buildings can result in several signals, or several groups of signals, arriving at a receiver. FIG. 1 illustrates a signal arriving in time as several signals. FIG. 2 illustrates a signal arriving in time as two groups of several signals. The multiple signals arriving at the receiver usually do not arrive with a uniform spread over time. Thus, in a multipath environment, a received signal r(t) may include two or more groups of spread-spectrum signals.

In the multipath environment, a spread-spectrum signal is assumed to generate a plurality of groups of spread-spectrum signals, with each group having a plurality of spread-spectrum signals. The plurality of groups is the result of the spread-spectrum signal reflecting in a multipath environment. As a means of responding to and dealing with this plurality of groups, the multipath processor is an improvement to a spread-spectrum receiver system.

In the exemplary arrangement shown in FIG. 3, a multipath processor for tracking a spread-spectrum signal is shown. The multipath processor is used as part of a spread-spectrum receiver system.

The multipath processor includes first despreading means, 25 second despreading means, first combining means, second combining means, and selecting means or output-combining means. The first combining means is coupled between the first despreading means and the selecting means or the output-combining signal. The second combining means is coupled between the second despreading means and the selecting means or the output-combining means.

The first despreading means despreads a received signal having a first plurality of spread-spectrum signals within a first group. The first despreading means thus generates a first plurality of despread signals. The first combining means combines, or adds together, the first plurality of despread signals to generate a first combined-despread signal.

The second despreading means despreads the received signal having a second plurality of spread-spectrum signals within a second group. The second despreading means thereby generates a second plurality of despread signals. The second combining means combines, or adds together, the second plurality of despread signals as a second combined-despread signal.

The selecting means selects either the first combined-despread signal or the second combined-despread signal. The selected combined-despread signal is outputted from the selecting means as an output-despread signal. The selecting means may operate responsive to the stronger signal strength of the first combined-despread signal and the second combined-despread signal, least mean square error, a maximum likelihood, or other selection criteria. Alternatively, using output-combining means in place of selecting means, the outputs of the first combining means and the second combining means may be coherently combined or added together, after suitable weighting.

As shown in FIG. 3, the first despreading means may include a first plurality of correlators for despreading, respectively, the first plurality of spread-spectrum signals. The first plurality of correlators is illustrated, by way of example, as first multiplier 111, second multiplier 112, third multiplier 113, first filter 121, second filter 122, third filter 123, first chipping-sequence signal g(t), second chipping-sequence signal $g(t-T_o)$, and third chipping-sequence signal $g(t-2T_o)$ The second chipping-sequence signal $g(t-T_o)$ and the third chipping-sequence signal $g(t-2T_o)$ are the same as the first chipping-sequence signal g(t), but delayed by time T_o and time $2T_o$, respectively. The delay between each chipping-sequence signal, preferably, is a fixed delay T_o.

At the input is received signal r(t). The first multiplier 111 is coupled between the input and the first filter 121, and to

a source of the first chipping-sequence signal g(t). The second multiplier **112** is coupled between the input and the second filter **122**, and to a source of the second chipping-sequence signal $g(t-T_o)$. The third multiplier **113** is coupled between the input and the third filter **123**, and to a source of the third chipping-sequence signal $g(t-2T_o)$. The outputs of the first filter **121**, the second filter **122** and the third filter **123** are coupled to the first adder **120**.

Circuitry and apparatus are well known in the art for generating chipping-sequence signals with various delays. Referring to FIG. 4, a chipping-sequence generator **401** is coupled to a voltage-controlled oscillator **402**, and a plurality of delay devices **403**, **404**, **405**, **406**. The voltage-controlled oscillator receives a group-delay signal. The group-delay signal corresponds to the time delay that the group of chipping-sequence signals used for despreading a particular group of received signals. The voltage-controlled oscillator **402** generates an oscillator signal. The chipping-sequence generator **401** generates the first chipping-sequence signal g(t) from the oscillator signal, with an initial position of the first chipping-sequence signal g(t) determined from the group-delay signal. The first chipping-sequence signal g(t) is delayed by the plurality of delay devices **403**, **404**, **405**, **406**, to generate the second chipping-sequence signal $g(t-T_o)$, the third chipping-sequence signal $g(t-2T_o)$, the fourth chipping-sequence signal $(gt-3T_o)$, etc. Thus, the second chipping-sequence signal $g(t-T_o)$ and the third chipping-sequence signal $g(t-2T_o)$ may be generated as delayed versions of the first chipping-sequence signal g(t). Additionally, acquisition and tracking circuitry are part of the receiver circuit for acquiring a particular chipping-sequence signal embedded in a received spread-spectrum signal.

Optionally, the multipath processor of FIG. 3 may include first weighting device **131**, second weighting device **132** and third weighting device **133**. The first weighting device **131** is coupled to the output of the first filter **121**, and a source of a first weighting signal W_1. The second weighting device **132** is coupled to the output of the second filter **122**, and to a source of the second weighting signal W_2. The third weighting device **133** is coupled to the output of the third filter **123** and to a source of the third weighting signal W_3. The first weighting signal W_1, the second weighting signal W_2 and the third weighting signal W_3 are optional, and my be preset within the first weighting device **131**, the second weighting device **132** and the third weighting device **133**, respectively. Alternatively, the first weighting signal W_1, the second weighting signal W_2, and the third weighting signal W_3 may be controlled by a processor or other control circuitry. The outputs of the first filter **121**, the second filter **122**, and the third filter **123** are coupled through the first weighting device **131**, the second weighting device **132** and the third weighting device **133**, respectively, to the first adder **120**.

Similarly, the second despreading means may include a second plurality of correlators for despreading the second plurality of spread-spectrum signals. The second plurality of correlators is illustrated, by way of example, as fourth multiplier **114**, fifth multiplier **115**, sixth multiplier **116**, fourth filter **124**, fifth filter **125**, sixth filter **126**, fourth chipping-sequence signal $g(t-T_{D1})$, fifth chipping- sequence signal $g(t-T_o-T_{D1})$, and sixth chipping-sequence signal $g(g-2T_o-T_{D1})$. The fourth multiplier **114** is coupled between the input and the fourth filter **124**, and a source of the fourth chipping-sequence signal $g(t-T_{D1})$. The fifth multiplier **115** is coupled between the input and the fifth filter **125** and a source of the fifth chipping-sequence signal $g(t-T_o-T_{D1})$. The sixth multiplier **116** is coupled between the input and the sixth filter **126**, and a source of the sixth chipping-sequence signal $g(t-2T_o-T_{D1})$. The fourth chipping-sequence signal $g(t-T_{D1})$, the fifth chipping-sequence signal $g(t-T_o-T_{D1})$ and the sixth chipping-sequence signal $g(t-2T_o-T_{D1})$ are the same as the first chipping-sequence signal g(t), but delayed by time T_{D1}, time T_o+T_{D1}, and time $2T_o+T_{D1}$, respectively. The second plurality of correlators thereby generates the second plurality of despread signals. The outputs of the fourth filter **124**, the fifth filter **125** and the sixth filter **126** are coupled to the second adder **130**.

At the output of the fourth filter **124**, the fifth filter **125**, and the sixth filter **126**, optionally, may be fourth weighting device **134**, fifth weighting device **135**, and sixth weighting device **136**. The fourth weighting device **134**, fifth weighting device **135**, and sixth weighting device **136** are coupled **15** to a source which generates fourth weighting signal W_4, fifth weighting signal W_5, and sixth weighting signal W_6, respectively. The fourth weighting signal W_4, the fifth weighting signal W_5, and the sixth weighting signal W_6 are optional, and may be preset within the fourth weighting device **134**, the fifth weighting device **135**, and the sixth weighting device **136**, respectively. Alternatively, the fourth weighting signal W_4, the fifth weighting signal W_5, and the sixth weighting signal W_6 may be controlled by a processor or other control circuitry. The outputs of the fourth filter **124**, fifth filter **125**, and sixth filter **126** are coupled through the fourth weighting device **134**, fifth weighting device, **135** and sixth weighting device **136**, respectively, to the second adder **130**. The output of the first adder **120** and the second adder **130** are coupled to the decision device **150**. The decision device **150** may be a selector or a combiner.

The weighting devices may be embodied as an amplifier or attenuation circuits, which change the magnitude and phase. The amplifier or attenuation circuits may be implemented with analog devices or with digital circuitry. The amplifier circuit or attenuation circuit may be adjustable, with the gain of the amplifier circuit or attenuation circuit controlled by the weighting signal. The use of a weighting signal with a particular weighting device is optional. A particular weighting device may be designed with a fixed weight or a preset amount, such as a fixed amount of amplifier gain.

FIG. **5** is a tapped-delay-line model of a communications channel. A signal s(t) entering the communications channel passes through a plurality of delays **411**, **412**, **413**, **414**, modeled with time T_o. The signal s(t), for each delay, is attenuated **416**, **417**, **418** by a plurality of complex attenuation factors h^n and adder **419**. The OUTPUT from the adder **419** is the output from the communications channel.

A given communications channel has a frequency response which is the Fourier transform of the impulse response.

$$H(f) = \sum_{i=1}^{N} a_i e^{-j2\pi f \tau_i}$$

where a_i represents the complex gains of the multipaths of the communications channel, and τ_i represents the delays of the multipaths of the communications channel.

Consider the communications-channel-frequency response, $H_c(f)$. The communications-channel-frequency response has a band of interest, B. Hereafter, this band of interest is fixed, and the communications-channel-frequency response $H_c(f)$ is the equivalent lowpass filter function. The

communications-channel-frequency response expands in Fourier series as

$$H_c(f)=\Sigma h_n e^{-jn2\pi f/B}$$

where h_n represents Fourier coefficients. This is a tapped-delay-line model of the communications channel for which the receiver in FIG. 3 acts as a matched filter when $T_o=1/B$, and the weights W_n are set to the complex conjugate of the values h_n. That is, $W_n=h_n$.

Preferably, each correlator of the first plurality of correlators despreads with a chipping-sequence signal g(t) which has a time delay different from each time delay of each chipping-sequence signal used, respectively, with each of the other correlators of the first plurality of correlators. The first plurality of correlators uses chipping-sequence signals g(t), $g(t-T_o)$, $g(t-2T_o)$, where T_o is the time delay between chipping-sequence signals. The time delay T_o may be the same or different between each chipping-sequence signal. For illustrative purposes, time delay T_o is assumed to be the same.

Similarly, each correlator of the second plurality of correlators despreads with a chipping-sequence signal having a time delay different from each time delay of each other chipping-sequence signal used, respectively, with each of the other correlators of the second plurality of correlators. Also, each correlator of the second plurality of correlators despreads with a chipping-sequence signal having the time delay T_{D1} different from each time delay of each chipping-sequence signal used with each respective correlator of the first plurality of correlators. Thus, the second plurality of correlators uses chipping-sequence signals $g(t-T_{D1})$, $g(t-T_o-T_{D1})$, $g(t-2T_o-T_{D1})$, where time delay T_{D1} is the time delay between the first plurality of correlators and the second plurality of correlators. The time delay T_{D1} is also approximately the same time delay as between the first received group of spread-spectrum signals and the second received group of spread-spectrum signals.

FIG. 6 illustrates a correlator, where an input signal s(t) is multiplied by multiplier 674 by a delayed version of the input signal s(t−T). The product of the two signals is filtered by the filter 675, and the output is the autocorrelation function R(T). The autocorrelation function R(T) for a square wave input signal s(t) is shown in FIG. 7. Over a chip time T_c, the correlation function R(T) is maximized when points A and B are equal in amplitude. A circuit which is well known in the art for performing this function is shown in FIG. 8. In FIG. 8, the despread signal s(t) is delayed by a half chip time $T_c/2$, and forwarded by half a chip time $T_c/2$. Each of the three signals are multiplied by the received signal r(t). The outputs of the delayed and forwarded multiplied signals are filtered, and then amplitude detected. The two filtered signals are combined by subtracting the delayed version from the forwarded version, and the difference or error signal is used to adjust the timing of the chipping-sequence signal used to despread signal s(t). Accordingly, if the delayed version were ahead of the forwarded version, the chipping-sequence signal for despread signal s(t) would be delayed. Likewise, if the forwarded version were ahead of the delayed version, then the chipping-sequence signal for despreading signal s(t) would be advanced. These techniques are well known in the art.

A similar technique is used for estimating a pilot signal from a received signal r(t), which has passed through a multipath environment. Referring to FIG. 9, the lower part of the diagram shows correlators corresponding to the correlators previously shown in FIG. 3. The upper part of the diagram shows the received signal processed by delayed versions of the pilot chipping-sequence signal $g_p(t)$. In FIG. 9, the received signal r(t) is multiplied by the pilot signal $g_p(t)$, and a plurality of delayed versions of the pilot signal $g_p(t-T_o)$, . . . , $g_p(t-kT_o)$ by a plurality of multipliers 661, 651, 641. The output of the plurality of multipliers 661, 651, 641, are each filtered by a plurality of filters 662, 652, 642, respectively. The output of the plurality of filters 662, 652, 642 are multiplied by a second plurality of multipliers 663, 653, 643 and respectively filtered by a second plurality of filters 664, 654, 644. The outputs of the second plurality of filters 664, 654, 644 are processed through a plurality of complex conjugate devices 665, 655, 645. The outputs of the plurality of complex conjugate devices 665, 655, 645 are the plurality of weights W_1, W_2, W_k, respectively. The plurality of weights are multiplied by the output of the first plurality of filters 662, 652, 642, by a third plurality of multipliers 666, 656, 646, and then combined by the combiner 667. At the output of the combiner 667 is a combined-despread-pilot signal.

Each of the second plurality of pilot filters 664, 654, 644 has a bandwidth which is approximately equal to the fading bandwidth. This bandwidth typically is very narrow, and may be on the order of several hundred Hertz.

Referring to FIG. 10, the output of the combiner 667 is multiplied by a fourth multiplier 668, and passed through an imaginary device 669 for determining the imaginary component of the complex signal from the fourth multiplier 668. The output of the imaginary device 669 passes through a loop filter 672 to a voltage controlled oscillator 673 or a numerically controlled oscillator (NCO). The output of the voltage controlled oscillator 673 passes to the fourth multiplier 668 and to each of the second plurality of multipliers 663, 653, 643.

Referring to FIG. 11, the foregoing circuits can generate a cross-correlation function between the received signal and a referenced pilot-chipping signal as a function of referenced delay, or lag. As shown in FIG. 11, these points of cross-correlation can have a center of gravity. The center of gravity is determined when the left mass equals the right mass of the correlation function, as shown in FIG. 12. A circuit similar to that shown in FIG. 8, coupled to the output of the fourth multiplier 668, can be used for aligning a chipping-sequence signal of the pilot channel.

As an alternative embodiment, as shown in FIG. 13, the first despreading means may include a first plurality of matched filters for despreading the received signal r(t) having the first plurality of spread-spectrum signals. At the output of the first plurality of matched filters is the first plurality of despread signals. Each matched filter of the first plurality of matched filters has an impulse response h(t), $h(t-T_o)$, $h(t-2T_o)$ etc., with a time delay T_o offset from the other matched filters. Referring to FIG. 13, by way of example, a first matched filter 141 is coupled between the input and through the first weighting device 131 to the first adder 120. A second matched filter 142 is coupled between the input and through the second weighting device 132 to the first adder 120. A third matched filter 143 is coupled between the input and through the third weighting device 133 to the first adder 120. As mentioned previously, the first weighting device 131, the second weighting device 132, and the third weighting device 133 are optional. The first weighting device 131, the second weighting device 132, and the third weighting device 133 generally are connected to a source of the first weighting signal W_1, the second weighting signal W_2, and the third weighting signal W_3, respectively. The first plurality of matched filters generates the first plurality of despread signals.

Similarly, the second despreading means may include a second plurality of matched filters for despreading the received signal r(t) having the second plurality of spread-spectrum signals. Accordingly, at the output of the second plurality of matched filters is the second plurality of despread signals. Each matched filter of the second plurality of matched filters has an impulse response, $h(t-T_{D1})$, $h(t-T_o-T_{D1})$, $h(t-2T_o-T_{D1})$, etc., with a time delay T_o offset from the other matched filters and with a time delay T_{D1} offset from the first plurality of matched filters. A fourth matched filter **144** is coupled between the input and through the fourth weighting device **134** to the second adder **130**. A fifth matched filter **145** is coupled between the input, and through the fifth weighting device **135** to the second adder **130**. A sixth matched filter **146** is coupled between the input and through the sixth weighting device **136** to the second adder **130**. As mentioned previously, the fourth weighting device **134**, the fifth weighting device **135**, and the sixth weighting device **136** are optional. The fourth weighting device **134**, the fifth weighting device **135**, and the sixth weighting device **136**, are coupled respectively to a source for generating the fourth weighting signal W_4, the fifth weighting signal W_5, and the sixth weighting signal W_6. Also, as with the correlator embodiment, the first adder **120** and the second adder **130** are coupled to the decision device **150**. The decision device **150** may be embodied as a selector or a combiner.

The present invention may further include despreading spread-spectrum signals located within a third group. Accordingly, the present invention may include third despreading means and third combining means. The third combining means is coupled between the third despreading means and the selecting means.

As shown in FIG. 14, the third despreading means despreads the received signal r(t) received as a third plurality of spread-spectrum signals within a third group. Accordingly, the third despreading means generates a third plurality of despread signals. The third combining means combines the third plurality of despread signals as a third combined-despread signal. The selecting means selects one of the first combined-despread signal, the second combined-despread signal or the third combined-despread signal. The output of the selecting means is the output-despread signal.

As shown in FIG. 14, the third despreading means may include a third plurality of correlators for despreading the third plurality of spread-spectrum signals. The third plurality of correlators is illustrated multiplier **117**, eighth with seventh multiplier **117**, eighth multiplier **118**, ninth multiplier **119**, seventh filter **127**, eighth filter **128**, ninth filter **129**, and a source for generating the seventh chipping-sequence signal $g(t-T_{D2})$, the eighth chipping-sequence signal $g(t-T_o-T_{D2})$, and the ninth chipping-sequence signal $g(t-2T_o-T_2)$. The seventh multiplier **117** is coupled between the input and the seventh filter **127**. The eighth multiplier **118** is coupled between the input and the eighth filter **128**. The ninth multiplier **119** is coupled between the input and the ninth filter **129**. The seventh multiplier **117**, the eighth multiplier **118**, and the ninth multiplier **119**, are coupled to the source for generating the seventh chipping-sequence signal, the eighth chipping-sequence signal and the ninth chipping-sequence signal, respectively. Optionally, at the output of the seventh filter **127**, eighth filter **128**, and ninth filter **129**, may be seventh weighting device **137**, eighth weighting device **138**, and ninth weighting device **139**, respectively. Accordingly, the output of the seventh filter **127** is coupled through the seventh weighting device **137** to the third adder **140**. The output of the eighth filter **128** is coupled through the eighth weighting device **138** to the third adder **140**. The output of the ninth multiplier **129** is coupled through the ninth weighting device **139** to the third adder **140**. The third adder is coupled to the decision device **150**. At the output of the third plurality of correlators is the third plurality of despread signals, respectively.

Preferably, each correlator of the third plurality of correlators despreads with a chipping-sequence signal $g(t-T_{D2})$, $g(t-T_o-T_{D2})$, $g(t-2T_o-T_{D2})$ having a time delay T_o different from each time delay of each chipping-sequence signal used with other correlators of the third plurality of correlators. Also, each correlator of the third plurality of correlators despreads with a chipping-sequence signal having a time delay different from each time delay of each chipping-sequence signal used, respectively, with each correlator of the second plurality of correlators. Also, each correlator of the third plurality of correlators despreads with a chipping-sequence signal having a time delay $2T_D$ different from each chipping-sequence signal used with each correlator of the first plurality of correlators.

Alternatively, the third despreading means may include, as shown in FIG. 15, a third plurality of matched filters for despreading the third plurality of spread-spectrum signals. The third plurality of matched filters includes seventh matched filter **147**, eighth matched filter **148**, and ninth matched filter **149**. The seventh matched filter is coupled between the input and through the seventh weighting device **137** to the third adder **140**. The eighth matched filter **148** is coupled between the input and through the eighth weighting device **138** to the third adder **140**. The ninth matched filter **149** is coupled between the input and through the ninth weighting device **139** to the third adder **140**. The third adder **140** is coupled to the decision device **150**. At the output of the third plurality of matched filters is the third plurality of despread signals.

The present invention may include fourth despreading means and fourth combining means, with the fourth combining means coupled between the fourth despreading means and the selecting means. The fourth despreading means would despread a fourth plurality of spread-spectrum signals within a fourth group. The output of the fourth despreading means would be a fourth plurality of despread signals. The fourth combining means would combine the fourth plurality of despread signals as a fourth combined-despread signal. The selecting means selects one of the first combined-despread signal, the second combined-despread signal, the third combined-despread signal, or the fourth combined-despread signal, as the output-despread signal.

In a similar fashion, the fourth despreading means includes a fourth plurality of correlators, or a fourth plurality of matched filters, for despreading the fourth plurality of spread-spectrum signals for generating the fourth plurality of despread signals. Each correlator of the fourth plurality of correlators would despread with a chipping-sequence signal having a time delay different from each time delay of each chipping-sequence signal used, respectively, with other correlators of the fourth plurality of correlators. Also, the chipping-sequence signal would be different from the chipping-sequence signals used with each correlator of the third plurality of correlators, each chipping-sequence signal used with each correlator of the second plurality of correlators, and each chipping-sequence signal used with each correlator of the first plurality of correlators. Based on the disclosure herein, a person skilled in the art would readily know how to extend the concept to a fifth group of spread-spectrum signals, or more generally, to a plurality of groups of spread-spectrum signals.

Each of the matched filters may be realized using surface-acoustic-wave (SAW) devices, digital matched filters, or embodied in an application specific integrated circuit (ASIC) chip or a digital signal processor (DSP) chip. Techniques for designing matched filters using these devices are well known in the art.

A multipath processor can single out individual paths from a group of rays. The weight for each weighting device is figured out by sets of correlators, and with a reference code it is possible to track the chipping-sequence signal in each ray.

Alternatively, a method using a multipath processor may be used for tracking a spread-spectrum signal within a plurality of groups. The method comprises the steps of despreading the received signal r(t) received as the first plurality of spread-spectrum signals within a first group to generate a first plurality of despread signals. The first plurality of despread signals are then combined as a first combined-despread signal. The method would include despreading the received signal received as a second plurality of spread-spectrum signals within a second group to generate a second plurality of despread signals. The second plurality of despread signals would be combined as a second combined-despread signal. The method includes selecting either the first combined-despread signal or the second combined-despread signal, as an output-despread signal.

The step of despreading the first plurality of spread-spectrum signals may include the step of correlating or matched filtering the first plurality of spread-spectrum signals, using a first plurality of correlators or a first plurality of matched filters, respectively. The step of despreading the second plurality of spread-spectrum signals may include the step of correlating or matched filtering the second plurality of spread-spectrum signals using a second plurality of correlators or a second plurality of matched filters, respectively.

The method may further include despreading a third plurality of spread-spectrum signals within a third group to generate a third plurality of despread signals. The third plurality of despread signals would be combined as a third combined-despread signal. The selecting step would thereby include selecting one of the first combined-despread signal, the second combined-despread signal or the third combined-despread signal, as the output-despread signal. Similarly, the step of despreading the third plurality of spread-spectrum signals may include the step of correlating or matched filtering the third plurality of spread-spectrum signals using a third plurality of correlators or a third plurality of matched filters, respectively.

The step of despreading each of the first plurality of spread-spectrum signals would include the step of despreading with a chipping-sequence signal having a time delay different from each time delay of each chipping-sequence signal used to despread other spread-spectrum signals of the first plurality of spread-spectrum signals. Similarly, the step of despreading each of the second plurality of spread-spectrum signals would include the step of despreading with a chipping-sequence signal having a time delay different from each time delay of each chipping-sequence signal used to despread other spread-spectrum signals of the second plurality of spread-spectrum signals. Also, the step of despreading each of the second plurality of spread-spectrum signals would include the step of despreading with a chipping-sequence signal having a time delay different from each time delay of each chipping-sequence signal used to despread other spread-spectrum signals of the first plurality of spread-spectrum signals.

In the event the method includes the step of despreading a third plurality of spread-spectrum signals, the method would include the steps of despreading with a chipping-sequence signal having a time delay different for each time delay of each chipping-sequence signal used to despread other spread-spectrum signals of the third plurality of spread-spectrum signals. Also, the time delay would be different for each chipping-sequence signal used to despread spread-spectrum signals of the second plurality of spread-spectrum signals, and different from each time delay of each chipping-sequence signal used to despread spread-spectrum signals of the first plurality of spread-spectrum signals.

The method may be extended to a fourth, fifth or plurality of groups of spread-spectrum signals.

Variable Bandwidth Filter

The present invention also includes a variable-bandwidth spread-spectrum-device for use with a spread-spectrum transmitter. The variable-bandwidth spread-spectrum device generates a spread-spectrum signal having a spread bandwidth. The term "spread bandwidth", as used herein, denotes the bandwidth of the transmitted spread-spectrum signal. The variable-bandwidth spread-spectrum device uses a chipping-sequence signal having a chipping rate which is less than the spread bandwidth. The term "chipping rate", as used herein, denotes the bandwidth of the chipping-sequence signal.

The variable-bandwidth spread-spectrum device includes first generating means, second generating means, spread-spectrum processing means, and filtering means. The spread-spectrum processing means is coupled to the first generating means. The second generating means is coupled between the spread-spectrum processing means and the filtering means.

The first generating means generates the chipping-sequence signal with the chipping rate. The spread-spectrum processing means processes a data signal with the chipping-sequence signal to generate a spread-data signal. The second generating means generates an impulse signal, in response to each chip of the spread-data signal. The filtering means filters the spectrum of each impulse signal with a bandpass equal to the spread bandwidth.

As illustratively shown in FIG. 16, the first generating means may be embodied as a chipping-sequence generator 161, the second generating means may be embodied as am impulse generator 165, the spread-spectrum processing means may be embodied as an EXCLUSIVE-OR gate product device 164, or other device known to those skilled in the art for mixing a data signal with a chipping-sequence signal, and the filtering means may be embodied as a filter 166.

The product device 164 is coupled to the chipping-sequence generator 161. The impulse generator 165 is coupled between the product device 164 and the filter 166.

The chipping-sequence generator 161 generates the chipping-sequence signal with the chipping rate. The product device 164 processes the data signal with the chipping-sequence signal, thereby generating a spread-data signal as shown in FIG. 17. The impulse generator 165 generates an impulse signal, as shown in FIG. 18, in response to each chip in the spread-data signal shown in FIG. 17. Each impulse signal of FIG. 18 has an impulse bandwidth. The term "impulse bandwidth", as used herein, denotes the bandwidth of the impulse signal. While theoretically an impulse signal has infinite bandwidth, practically, the impulse signal has a bandwidth which is greater than the spread bandwidth.

The filter 166 has a bandwidth adjusted to the spread bandwidth. Thus, the filter 166 filters a spectrum of each impulse signal of the spread-data signal with the spread bandwidth. The filter 166 does this for each impulse signal.

The filter 166 preferably includes a variable-bandwidth filter. The variable-bandwidth filter may be used for varying or adjusting the spread bandwidth of the spectrum for each impulse signal. Accordingly, a spread-spectrum signal may be designed having the bandwidth of choice, based on the bandwidth of the variable-bandwidth filter. The bandwidth may be variable, or adjustable, as would be required for particular system requirements. As used in this patent, a variable bandwidth is one that is able to vary according to time conditions, background signals or interference, or other requirements in a particular system. An adjustable bandwidth would be similar to a variable bandwidth, but is used to refer to a bandwidth which may be adjusted to remain at a chosen setting.

The first generating means, as shown in FIG. 19, may include a frequency-domain-chipping-sequence generator 161 and an inverse-Fourier-transform device 162. The frequency-domain-chipping-sequence generator 161 may be used to generate a frequency-domain representation of a chipping-sequence signal. The inverse-Fourier-transform device 162 transforms the frequency-domain representation of the chipping-sequence signal to the chipping-sequence signal.

The first generating means may further include a memory 163 for storing the chipping-sequence signal.

The present invention also includes a variable-bandwidth spread-spectrum method for use with a transmitter. The method includes the steps of generating the chipping-sequence signal with the chipping rate, and spread-spectrum processing a data signal with the chipping-sequence signal to generate a spread-data signal. Each chip in the spread-spectrum signal is used to generate an impulse signal. Each impulse signal is filtered with the spread bandwidth to generate the desired bandwidth signal.

Thus, the variable-bandwidth-spread-spectrum device uses a lower chip rate, but provides a wider bandwidth signal. The power spectral density at the output of the filter 166 of the filtered-spread-data signal s(t) is proportional to the frequency response s(f) of the filter.

$$PSD_{s(t)}=k|H(f)|^2$$

Thus, the filter 166 controls the shape of the spectrum of the filtered-spread-data signal.

The processing gain (PG) is bandwidth W of the filtered-spread-data signal divided by chip rate R_b of the filtered-spread-data signal.

$$PG=W/R_b$$

The capacity N of the filtered-spread-data signal is

$$N \leq \frac{PG}{E_b/N_o}+1$$

The capacity does not depend on chip rate, but instead on bandwidth. One can achieve an upper bound on the capacity if the chip rate is greater than the bandwidth. But, if the chip rate were lower, then one can save power consumption, i.e., use a lower clock rate of CMOS, which determines power consumption.

Adaptive Power Control System

The present invention assumes that a plurality of mobile stations operate in a cellular-communications network using spread-spectrum modulation. The cellular communications network has a plurality of geographical regions, with a multiplicity of cells within each geographical region. The size of the cells in a first geographical region may differ from the size of the cells in a second geographical region. In a first geographical region, such as an urban environment, the cellular architecture may have a large number of cells, each of small area, which place the corresponding base station close to each other. In a second geographical region, such as a rural environment, the cellular architecture may have a smaller number of cells, each of larger area. Further, the size of the cells may vary even within a specified geographic region.

A mobile station, while in the urban environment of the first geographical region, may be required to transmit at a lower power level than while in the rural environment of the second geographical region. This requirement might be due to a decreased range of the mobile station from the base station. Within a particular cell, a mobile station near the base station of the cell may be required to transmit with a power level less than that required when the mobile station is near an outer perimeter of the cell. This adjustment in power level is necessary to ensure a constant power level is received at the base station from each mobile station.

Adaptive power control works by measuring the received signal to noise ratio (SNR) for each user and causing the user transmitted power to vary in a manner to cause all users' SNR's to be equal to a common value which will be adequate for reliable communication if the total number of users and interference is less than system capacity. While this assumes that all users are obtaining the same service, e.g., 32 kbs voice data, it is a feature of the system described that different service options are supported for requesting users. This is done by adjusting the setpoint for each user independently.

There are two issues that arise when addressing the base operation of an adaptive power control system. The first is the common value obtained for SNR versus the load and its cost to the transmitters in terms of transmitted power, and the second is the stability of the system. Stability means that a perturbation of the system from its quiescent state causes a reaction of the system to restore the quiescent condition. It is highly desirable that there exist only one quiescent point because otherwise "chatter" or oscillation may occur. Stability must be addressed with any control system but, in the present case, the situation is somewhat complicated by the fact that the users affect one another, and thereby cause the control variables, the transmitted power and resulting SNR's, to be dynamically coupled. The coupling is apparent when one realizes that all signals are processed by a common AGC function which does not discriminate individual user signals from each other or from other sources.

The power control scheme of the present invention is a closed loop scheme. The system measures the correlator output power for each user and compares the measured value with a target value or setpoint. This measured power includes both the desired signal component and unwanted power or noise.

The AGC maintains the total power into each correlator at a preset level. This level does not vary as a function of APC action; that is, this role of the AGC is independent of APC. Furthermore, an increase in received power from any user or subset of users will be "attacked" by the AGC. This is

possible because the AGC time constant is smaller than the APC time constant, i.e., the AGC is faster than the APC. Since the total power available out of the AGC is fixed, an increase in the portion due to one user comes at the expense of all other users. While this may work against the apparent stability of the system, the AGC sensor, which measures the AGC control signal and thereby measures the total received power, causes the system to seek a quiescent state corresponding to the minimum received power per user. It is desired that the transmitted power be minimized because this will minimize intercell interference and conserve battery power. Excess transmitter power will be dissipated within the AGC as long as all users transmit excessive power.

The implementation shown in the figures is to be considered representative. In particular, the method of controlling the remote transmitter power via attenuators and variable gain amplifiers is perhaps redundant. Either or both of these means may be employed, depending upon the (dynamic) range of control required. Also, control may be caused at either IF or RF frequencies.

For discussion purposes, a mobile station within a particular cell transmits a first spread-spectrum signal, and the base station transmits a second spread-spectrum signal.

In the exemplary arrangement shown in FIG. 20, a block diagram of a base station as part of a system for adaptive-power control of a spread-spectrum transmitter is provided.

FIG. 20 illustrates the base station adaptive power control system with automatic gain control (AGC) means, power means, comparator means, transmitter means, and an antenna. The AGC means is shown as an automatic-gain-control (AGC) amplifier 228, correlator means is shown as despreader 231, and power means is shown as power measurement device 233. The comparator means is shown as comparator 239, the transmitter means is shown as power amplifier 237 coupled to the antenna 226. Also illustrated is a delta modulator 235 coupled between comparator 239 and power amplifier 237.

The AGC amplifier 228 is coupled to the despreader 231. The power measurement device 233 is coupled to the despreader 231. The comparator 239 is coupled to the output of the power measurement device 233 and to the AGC amplifier 228. The multiplexer 234 is coupled between the comparator 239 and the power amplifier 237. The delta modulator 235 is coupled between the power amplifier 237 and the multiplexer 234. The power amplifier 237 is coupled to the antenna 56.

A threshold level is used by the comparator 239 as a comparison for the received-power level measured by the power measurement device 233.

For each received signal, the AGC amplifier 228 generates an AGC-output signal and an AGC-control signal. The AGC-output signal is despread to obtain the signal of a first user using despreader 231. The despread-AGC-output signal from the despreader 231 is combined with the AGC-control signal from the AGC amplifier 228, by the combiner 241. The AGC-control signal from the AGC amplifier 228 may be offset by offset level S_1 using combiner 242, and weighted by weighting device 243. The weighting device 243 may be an amplifier or attenuator.

The received-power level from power device 233 may be offset by offset level S_2 using combiner 244, and weighted by weighting device 245. The weighting device 245 may be an amplifier or attenuator. The combiner 241 combines the AGC-control signal with the received-level signal, for generating adjusted-received-power level. The comparator 239 generates a comparison signal by comparing the adjusted-received-power level to the threshold level. The comparison signal may be an analog or digital data signal. The comparison signal indicates whether the mobile station is to increase or decrease its power level. If the adjusted-received-power level exceeds the threshold, for example, then the comparison signal sends a message to the mobile station to decrease its transmitter power. If the adjusted-received-power level were below the threshold, then the comparison signal sends a message to the mobile station to increase its transmitter power. The comparison signal is converted to a power-command signal by the delta modulator 235.

The power-command signal may be transmitted with or separate from the second spread-spectrum signal. For example, a spread-spectrum signal using a first chip sequence may be considered a first spread-spectrum channel, and a spread-spectrum signal using a second chip sequence may be considered a second spread-spectrum channel. The power-compound signal may be transmitted in the same spread-spectrum channel, i.e., the first spread-spectrum channel, as the second spread-spectrum signal, in which case the power-command signal is transmitted at a different time interval from when the second spread-spectrum signal is transmitted- This format allows the mobile station to acquire synchronization with the first sequence, using the second spread-spectrum signal. The power-command signal may also be transmitted in a second spread-spectrum channel which is different from the second spread-spectrum signal. In this case, the second spread-spectrum signal having the power-command signal would be acquired by the second chipping-sequence generator and second product device. The power-command signal may be time division multiplexed or frequency division multiplexed with the second spread-spectrum signal.

The base-correlator means is depicted in FIG. 20 as first despreader 231. The system, by way of example, may have the base-correlator means embodied as a product device, a chip-sequence generator, and a bandpass filter. Alternatively, the base-correlator means may be realized as a matched filter such as a surface-acoustic-wave device, or as a digital matched filter embodied in a digital signal processor. In general, the base-correlator means uses or is matched to the chip sequence of the spread-spectrum signal being received. Correlators and matched filters for despreading a spread-spectrum signal are well known in the art.

Typically, the AGC circuit 228 is coupled to a low noise amplifier 227, through an isolator 225 to the antenna 226. In FIG. 20 a plurality of despreaders, despreader 229 through despreader 231, are shown for despreading a plurality of spread-spectrum channels which may be received from a plurality of mobile stations. Similarly, the output of each despreader 229 25 through despreader 231 is coupled to a plurality of demodulators, illustrated as demodulator 230 through demodulator 232, respectively, for demodulating data from the despread AGC-output signal. Accordingly, a plurality of data outputs are available at the base station.

For a particular spread-spectrum channel, the first despreader 231 is shown coupled to power device 233 and multiplexer 234. The power device 233 typically is a power-measurement circuit which processes the despread AGC-output signal as a received-power level. The power device 233 might include an analog-to-digital converter circuit for outputting a digital received-power level. The comparator means, embodied as comparator circuit 239, compares the processed received-power level to a threshold. The multiplexer 234 is coupled to the output of the power device 233 through the comparator circuit 239. The multiplexer 234 may insert appropriate framing bits, as required.

The transmitter means may be embodied as a quadrature phase shift keying (QPSK) modulator or a delta modulator 235 coupled to a power amplifier 237. In FIG. 20, the input to the delta modulator 235 typically would have the power-command signal from the power device 233 multiplexed with data from the k^{th} channel. A plurality of spread spectrum channels would have their data and appropriate power-command signals combined by combiner 236 and amplified by power amplifier 237. The output of the power amplifier 237 is coupled through the isolator 125 to the antenna 226.

The power command signal is transmitted periodically. The period T might be chosen to be 250 microseconds in order to ensure a low root mean square error as well as a low peak error between the instantaneous received signal and the constant desired signal.

A mobile station is illustratively shown in FIG. 21. The mobile-despreading means is illustrated as despreader 334 and variable-gain means is illustrated as a variable-gain device 341. The variable-gain device 341 is coupled between the transmitter 342 and through isolator 336 to antenna 335. The despreader 334 is coupled to the isolator 336 and to demultiplexer 339. The output of the despreader 334 is also coupled to a demodulator 340. The despreader 334 may be embodied as an appropriate correlator, or matched filter, for despreading the k^{th} channel. Additional circuitry may be used, such as radio frequency (RF) amplifiers and filters, or intermediate frequency (IF) amplifiers and filters, as is well known in the art.

A received second spread-spectrum signal at antenna 335 passes through isolator 336 to despreader 334. The despreader 334 is matched to the chip sequence of the desired spread-spectrum channel. The output of the despreader 334 passes through the demodulator 340 for demodulating the data from the desired spread-spectrum channel. Additionally, the demultiplexer 339 demultiplexes the power-command signal from the despread signal outputted from despreader 334. The power-command signal drives the variable-gain device 341.

A decision device 345 and accumulator 346 may be coupled between the demultiplexer 339 and the variable gain device 341. A step-size-algorithm device 344 is coupled to the output of the decision device 345 and to the accumulator 346.

The step-size-algorithm device 344 stores an algorithm for adjusting the power level of the variable gain device 341. A nonlinear algorithm that might be used is shown in FIG. 22. FIG. 23 compares a nonlinear algorithm with a linear step size algorithm.

The power-command end signal from the demultiplexer 339 causes the decision device 345 to increase or decrease the power level of the variable gain device 341, based on the threshold of the step size algorithm shown in FIG. 23. The accumulator tracks previous power levels as a means for assessing the necessary adjustments in the step size of the power level pursuant to the algorithm as shown in FIG. 23.

The variable-gain device 341 may be embodied as a variable-gain amplifier, a variable-gain attenuator, or any device which performs the same function as the variable-gain device 341 as described herein. The variable-gain device 341 increases or decreases the power level of the remote station transmitter, based on the power-command signal.

As illustratively shown in FIG. 20, a block diagram of a power measurement circuit includes interference rejection for use with the base station. As shown in FIG. 20, the AGC amplifier 228 is connected to the despreader 231, and the output of the despreader 231 is connected to the power measurement circuit 233. Additionally, the AGC amplifier 228 is connected to the combiner 236 through the comparator 239.

A received signal includes a first spread-spectrum signal with power P_c and the other input signals which are considered to be interfering signals with power P_j at the input to the AGC amplifier 228 of FIG. 20. The interfering signal may come from one or more nondesirable signals, noise, multipath signals, and any other source which would serve as an interfering signal to the first spread-spectrum signal. The received signal is normalized by the AGC amplifier 228. Thus, by way of example, the AGC amplifier 228 can have the power output, $P_c+P_j=1$. The normalized received signal is despread by the despreader 231 to receive a particular mobile user's signal. The chipping-sequence generator of despreader 231 generates a chip-sequence signal using the same chip sequence as used by the first spread-spectrum signal. Alternatively, the matched filter, if used, of despreader 231 may have an impulse response matched to the same chip sequence as used by the first spread-spectrum signal. The output of the despreader 231 is the normalized power of the first spread-spectrum signal plus the normalized power of the interfering signal divided by the processing gain, PG, of the spread-spectrum system. The power measurement circuit 233 generates a received-power level of the first spread-spectrum signal. The comparator 239 processes the despread-received signal with the AGC-control signal and outputs the power-control signal of the first spread-spectrum signal. The power level of the interfering signal is reduced by the processing gain, PG.

The comparator 239 processes the AGC-control signal with the despread, normalized received signal by multiplying the two signals together, or by logarithmically processing the AGC-control signal with the despread-received signal. In the latter case, the logarithm is taken of the power of the received signal, P_c+P_j, and the logarithm is taken of the despread, normalized received signal. The two logarithms are added together to produce the received-power level.

For the present invention to work effectively, the despread signal must be kept nearly constant, independent of variations in the other signals or of obstructions. A preferred implementation to accomplish this end is shown in the circuitry of FIG. 20. FIG. 20 depicts a means for determining at the base station the power of the first spread-spectrum signal when the received signal includes multiple signals and noise. If the circuitry of FIG. 20 were not used, then it is possible that the interfering signal, which may include noise, multipath signals, and other undesirable signals, may raise the power level measured at the input to the receiver of the base station, thereby suppressing the first spread spectrum signal. The undesirable power level measured may cause the remote station to transmit more power than required, increasing the amount of power received at the base station.

As noted earlier, the APC system is a closed loop system. The APC loop operates by generating commands to increase or decrease the transmitter power at the update rate. This is actually quantization process that is done to limit the amount of information that must be fed back to the remote transmitter. The amount of increase or decrease may be fixed in advance or it may adapt in response to the characteristics of the channel as measured locally in the remote terminal, the terminal being controlled. In particular, the remote terminal may examine the sequence of commands received by it. A long sequence of increase commands, for example, implies that the step size may be increased. A typical scheme

increases the step size by a fixed amount or a fixed percentage whenever two successive bits are the same. For example, the step size may be increased by 50% if two bits in a row are the same and decreased by 50% if they differ. This is a fairly gross change in the step size, and is intended to be adaptive to local, or immediate in time, variations in the required transmitted power. This process results in a large variation of the step size with time.

An adaptive step size algorithm may also be considered in a different context. Specifically, the step size may be considered to be nearly constant or not responding to localized variations in demanded transmitted power, but the value may be automatically adjusted based on the global characteristics of the channel induced control action. Thus, in a nearly static environment one should use a small constant step size while in a mobile environment the step size should be larger.

Adjustment of the power level of the remote station transmitter may be effected either linearly or nonlinearly. The following algorithm will cause the step size to settle at a nearly optimum constant value. The receiver examines successive APC bits and increases the step size by the factor (1+x) if they agree and decreases the step size by the factor (1+x) if they disagree. Here the parameter x is small (x=0.01, for example.) While this procedure will not allow local adaptation (because x is small), it will result in an adaptation to global conditions. Specifically, if the transmitted APC bit stream exhibits a tendency toward successive bits in agreement (i.e., runs of 1's or 0's are evident) it implies that the system is not following the changes in channel conditions (i.e., the system is slow rate limited) and the step size should be increased. On the other hand, if successive bits tend to be opposite, the system is "hunting" for a value between two values that are excessively far apart. The statistics one expects to observe is optimal are intermediate to these extremes. That is, the APC bit stream should appear equally likely to contain the patterns (0,0), (0,1), (1,0), and (1,1) in any pair of successive bits. The above algorithm drives the system behavior toward this.

The above algorithm (global adaptation) works particularly well when the system employs a high update rate relative to the dynamics of the channel.

As illustrated in FIG. 23, to increase the power level using linear adjustment, for example, the transmitter power is increased in regular increments of one volt, or other unit as instructed by the base station, until the power level received at the base station is sufficiently strong. Linear adjustment may be time consuming if the power adjustment necessary were substantial.

As shown in FIG. 22, to increase the power using nonlinear adjustment, the transmitter voltage may be increased, by way of example, geometrically until the transmitted power is in excess of the desired level. Transmitter power may be then reduced geometrically until transmitted power is below the desired level. A preferred approach is to increase the step size voltage by a factor of 1.5 and to decrease the step size by a factor of 0.5. Other nonlinear algorithms may be used. As shown in FIG. 23, this process is repeated, with diminishing margins of error in both excess and insufficiency of desired power, until the desired signal level has been obtained. Nonlinear adjustment provides a significantly faster rise and fall time than does linear adjustment, and may be preferable if power must be adjusted significantly.

The system determines the error state (APC bit) every T sections, 1/T being the update rate of the control. The update

race may vary from 100 Hz, which is low, to 100 kHz, which is quite high. The opportunity to measure the error state of the system arises with each reception of a new symbol. Thus, the update race may be equal to the symbol rate. If such an update rate is not supported, it is beneficial to make use of the available error measurements by combining them (or averaging them) between updates. This minimizes the chance of causing a power adjustment in the wrong direction which can occur because of noise in the error signals themselves.

The choice of update rate depends on factors other than APC operation, namely, the amount of capacity and method of allocating capacity to the transport of the APC bits over the channel. In general, a faster update will produce superior performance, even if the increased update rate is obtained by permitting the APC bits to be received in error occasionally. Elaborating, a 1 kHz update rate with no channel induced errors will perform less effectively than a 100 kHz update rate at a 25% rate of errors. This is because of the self correcting behavior of the control loop. A faster update race eliminates the latency of control which is a key performance limiting phenomenon.

A spread spectrum base station receives all incoming signals simultaneously. Thus, if a signal were received at a higher power level than the ochers, then that signal's receiver has a higher signal-to-noise ratio and therefore a lower bit error race. The base station ensures that each mobile station transmits at the correct power level by telling the remote, every 500 microseconds, whether to increase or to decrease the mobile station's power.

FIG. 24 shows a typical fading signal which is received at the base station along with ten other independently fading signals and thermal noise having the same power as one of the signals. Note that the fade duration is about 5 milliseconds which corresponds to vehicular speed exceeding 60 miles per hour. FIGS. 25–26 illustrate the results obtained when using a particular adaptive power control algorithm. In this case, whenever the received signal changes power, the base station informs the remote and the remote varies its power by ±1 dB. FIG. 25 shows the adaptive power control signal at the remote station. FIG. 26 shows the received power at the base station. Note that the adaptive power control track the deep fades and as a result 9 dB fades resulted. This reduced power level resulted in a bit error rate of 1.4×10^{-2}.

For the same fade of FIG. 24, assume a different adaptive power control algorithm is employed as shown in FIGS. 27–28. In this case the control voltage results in the remote unit changing its power by a factor of 1.5 in the same direction, or by a factor of 0.5 in the opposite direction. In this particular implementation the minimum step size was 0.25 dB and the maximum step size was 4 dB. Note that the error is usually limited to ±2 dB with occasional decreases in power by 5 dB to 6 dB resulting in a BER~8×10^{-4}, a significant improvement compared to the previous algorithm. The use of interleaving and forward error correcting codes usually can correct any errors resulting from the rarely observed power dips.

In operation, a mobile station in a cell may transmit the first spread-spectrum signal on a continuous basis or on a repetitive periodic basis. The base station within the cell receives the first spread-spectrum signal. The received first spread-spectrum signal is acquired and despread with the chip-sequence signal from chip-sequence generator and product device. The despread first spread-spectrum signal is filtered through bandpass filter. The base station detects the

despread first spread-spectrum signal using envelope detector, and measures or determines the received-power level of the first spread-spectrum signal. The base station generates the power-command signal from the received-power level.

The present invention also includes a method for automatic-power control of a spread-spectrum transmitter for a mobile station operating in a cellular-communications network using spread-spectrum modulation, with the mobile station transmitting a first spread-spectrum signal. In use, the method includes the step of receiving a received signal, generating an AGC-output signal, despreading the AGC-output signal, processing the despread AGC-output signal to generate a received-power level, generating a power-command signal, transmitting the power-command signal as a second spread-spectrum signal, despreading the power-command signal from the second spread-spectrum signal as a power-adjust signal, and adjusting a power level of the first spread-spectrum signal.

The received signal includes the first spread-spectrum signal and an interfering signal and is received at the base station. The AGC-output signal is generated at the base station and despread as a despread AGC-output signal. The despread AGC-output signal is processed at the base station to generate a received-power level.

The received-power level is compared to a threshold, with the comparison used to generate a power-command signal. If the received-power level were greater than the threshold, the power-command signal would command the mobile station to reduce transmitter power. If the received-power level were less than the threshold, the power-command signal would command the mobile station to increase transmitter power.

The power-command signal is transmitted from the base station to the mobile station as a second spread-spectrum signal. Responsive to receiving the second spread-spectrum signal, the mobile station despreads the power-command signal as a power-adjust signal. Depending on whether the power-command signal commanded the mobile station to increase or decrease transmitter power, the mobile station, responsive to the power adjust signal, increases or decreases the transmitter-power level of the first spread-spectrum signal, respectively.

The method may additionally include generating from a received signal an AGC-output signal, and despreading the AGC-output signal. The received signal includes the first spread-spectrum signal and an interfering signal. The received signal is processed with the despread AGC-output signal to generate a received-power level. The method then generates a comparison signal by comparing the received-power level to the threshold level. While transmitting a second spread-spectrum signal, the method adjusts a transmitter-power level of the first spread-spectrum signal from the transmitter using the power-adjust signal.

It will be apparent to those skilled in the art that various modifications can be made to the spread-spectrum system and method of the instant invention without departing from the scope or spirit of the invention, and it is intended that the present invention cover modifications and variations of the spread-spectrum system and method provided they come within the scope of the appended claims and their equivalents.

I claim:

1. A multipath processor for tracking a spread-spectrum signal within a plurality of groups of spread-spectrum signals, each group having a plurality of spread-spectrum signals, said multipath processor comprising:

first means for despreading a first plurality of spread-spectrum signals within a first group, to generate, respectively, a first plurality of despread signals;

first means, coupled to said first despreading means, for combining the first plurality of despread signals as a first combined-despread signal;

second means for despreading a second plurality of spread-spectrum signals within a second group, to generate, respectively, a second plurality of despread signals;

second means, coupled to said second despreading means, for combining the second plurality of despread signals, as a second combined-despread signal; and

means, coupled to said first combining means and to said second combining means, for selecting one of the first combined-despread signal and the second combined-despread signal, as an output-despread signal.

2. The multipath processor as set forth in claim 1, wherein:

said first despreading means includes a first plurality of correlators for despreading, respectively, the first plurality of spread-spectrum signals, thereby generating the first plurality of despread signals; and

said second despreading means includes a second plurality of correlators for despreading, respectively, the second plurality of spread-spectrum signals, thereby generating the second plurality of despread signals.

3. The multipath processor as set forth in claim 2, wherein:

each correlator of said first plurality of correlators despreads with a chipping-sequence signal having a time delay different from each time delay of each chipping-sequence signal used with other correlators of said first plurality of correlators; and

each correlator of said second plurality of correlators despreads with a chipping-sequence signal having a time delay different from each time delay of each chipping-sequence signal used with other correlators of said second plurality of correlators, and having =he time delay different from each time delay of each chipping-sequence signal used with ocher correlators of said first plurality of correlators.

4. The multipath processor as set forth in claim 1, wherein:

said first despreading means includes a first plurality of matched filters for despreading, respectively, the first plurality of spread-spectrum signals, thereby generating the first plurality of despread signals; and

said second despreading means includes a second plurality of matched filters for despreading, respectively, the second plurality of spread-spectrum signals, thereby generating the second plurality of despread signals.

5. The multipath processor as set forth in claim 1, further comprising:

third means for despreading a third plurality of spread-spectrum signals within a third group, to generate, respectively, a third plurality of despread signals;

third means, coupled to said third despreading means, for combining the third plurality of despread signals as a third combined-despread signal; and

wherein said selecting means, coupled to said third combining means, selects one of the first combined-despread signal, the second combined-despread signal and the third combined-despread signal, as the output-despread signal.

6. The multipath processor as set forth in claim 5, wherein:

said first despreading means includes a first plurality of correlators for despreading, respectively, the first plurality of spread-spectrum signals, thereby generating the first plurality of despread signals;

said second despreading means includes a second plurality of correlators for despreading, respectively, the second plurality of spread-spectrum signals, thereby generating the second plurality of despread signals; and

said third despreading means includes a third plurality of correlators for despreading the third plurality of spread-spectrum signals, respectively, thereby generating the third plurality of spread-spectrum signals.

7. The multipath processor as set forth in claim 6, wherein:

each correlator of said first plurality of correlators despreads with a chipping-sequence signal having a time delay different from each time delay of each chipping-sequence signal used with other correlators of said first plurality of correlators;

each correlator of said second plurality of correlators despreads with a chipping-sequence signal having a time delay different from each time delay of each chipping-sequence signal used with other correlators of said second plurality of correlators, and having the time delay different from each time delay of each chipping-sequence signal used with other correlators of said first plurality of correlators; and

each correlator of said third plurality of correlators despreads with a chipping-sequence signal having a time delay different from each time delay of each chipping-sequence signal used with other correlators of said third plurality of correlators, having the time delay different from each time delay of each chipping-sequence signal used with other correlators of said second plurality of correlators, and having the time delay different from each time delay of each chipping-sequence signal used with other correlators of said first plurality of correlators.

8. The multipath processor as set forth in claim 5, wherein:

said first despreading means includes a first plurality of matched filters for despreading, respectively, the first plurality of spread-spectrum signals, thereby generating the first plurality of despread signals;

said second despreading means includes a second plurality of matched filters for despreading, respectively, the second plurality of spread-spectrum signals, thereby generating the second plurality of despread signals; and

said third despreading means includes a third plurality of matched filters for despreading, respectively, the third plurality of spread-spectrum signals, thereby generating the third plurality of despread signals.

9. The multipath processor as set forth in claim 5, further comprising:

fourth means for despreading a fourth plurality of spread-spectrum signals within a fourth group, to generate, respectively, a fourth plurality of despread signals;

fourth means, coupled to said fourth despreading means, for combining the fourth plurality of despread signals as a fourth combined-despread signal; and

wherein said selecting means, coupled to said fourth combining means, selects one of the first combined-despread signal, the second combined-despread signal, the third combined-despread signal and the fourth combined-despread signal, as the output-despread signal.

10. The multipath processor as set forth in claim 9, wherein:

said first despreading means includes a first plurality of correlators for despreading, respectively, the first plurality of spread-spectrum signals, thereby generating the first plurality of despread signals;

said second despreading means including a second plurality of correlators for despreading, respectively, the second plurality of spread-spectrum signals, thereby generating the second plurality of despread signals;

said third despreading means includes a third plurality of correlators for despreading the third plurality of spread-spectrum signals, respectively, for generating the third plurality of despread signals; and

said fourth despreading means includes a fourth plurality of correlators for despreading the fourth plurality of spread-spectrum signals, respectively, for generating the fourth plurality of despread signals.

11. The multipath processor as set forth in claim 10, wherein:

each correlator of said first plurality of correlators despreads with a chipping-sequence signal having a time delay different from each time delay of each chipping-sequence signal used with other correlators of said first plurality of correlators;

each correlator of said second plurality of correlators despreads with a chipping-sequence signal having a time delay different from each time delay of each chipping-sequence signal used with other correlators of said second plurality of correlators, and having the time delay different from each time delay of each chipping-sequence signal used with other correlators of said first plurality of correlators;

each correlator of said third plurality of correlators despreads with a chipping-sequence signal having the time delay different from each time delay of each chipping-sequence signal used with other correlators of said third plurality of correlators, having the time delay different from each time delay of each chipping-sequence signal used with other correlators of said second plurality of correlators, and having the time delay different from each time delay of each chipping-sequence signal used with other correlators of said first plurality of correlators; and

each correlator of said fourth plurality of correlators despreads with a chipping-sequence signal having the time delay different from each time delay of each chipping-sequence signal used with other correlators of said fourth plurality of correlators, having the time delay different from each time delay of each chipping-sequence signal used with other correlators of said third plurality of correlators, having the time delay different from each time delay of each chipping-sequence signal used with other correlators of said second plurality of correlators, and having the time delay different from each time delay of each chipping-sequence signal used with other correlators of said first plurality of correlators.

12. The multipath processor as set forth in claim 9, wherein:

said first despreading means includes a first plurality of matched filters for despreading the first plurality of spread-spectrum signals, thereby generating the first plurality of despread signals;

said second despreading means includes a second plurality of matched filters for despreading the second plurality of spread-spectrum signals, thereby generating the second plurality of despread signals;

said third despreading means includes a third plurality of matched filters for despreading, respectively, the third plurality of spread-spectrum signals, thereby generating the third plurality of despread signals; and

said fourth despreading means includes a fourth plurality of matched filters for despreading, respectively, the fourth plurality of spread-spectrum signals, thereby generating the fourth plurality of despread signals.

13. A method using a multipath processor for tracking a spread-spectrum signal within a plurality of groups of spread-spectrum signals, each group having a plurality of spread-spectrum signals, comprising the steps of:

despreading a first plurality of spread-spectrum signals within a first group, to generate, respectively, a first plurality of despread signals;

combining the first plurality of despread signals as a first combined-despread signal;

despreading a second plurality of spread-spectrum signals within a second group, to generate, respectively, a second plurality of despread signals;

combining the second plurality of despread signals, as a second combined-despread signal; and

selecting one of the first combined-despread signal and the second combined-despread signal, as an output-despread signal.

14. The method as set forth in claim 13, wherein:

the step of despreading the first plurality of spread-spectrum signal includes the step of decorrelating, respectively, the first plurality of spread-spectrum signals, thereby generating the first plurality of despread signals; and

the step of despreading the second plurality of spread-spectrum signal includes the step of decorrelating, respectively, the second plurality of spread-spectrum signals, thereby generating the second plurality of despread signals.

15. The method as set forth in claim 13, wherein:

the step of despreading each of the first plurality of spread-spectrum signals includes the step of despreading with a chipping-sequence signal having a time delay different from each time delay of each chipping-sequence signal used to despread other spread-spectrum signals of the first plurality of spread-spectrum signals; and

the step of despreading each of the second plurality of spread-spectrum signals includes the step of despreading with a chipping-sequence signal having a time delay different from each time delay of each chipping-sequence signal used to despread other spread-spectrum signals of the second plurality of spread-spectrum signals, and having the time delay different from each time delay of each chipping-sequence signal used to despread each spread-spectrum signal of the first plurality of spread-spectrum signals.

16. The method as set forth in claim 13, wherein:

the step of despreading the first plurality of spread-spectrum signals includes the step of filtering the first plurality of spread-spectrum signals, thereby generating the first plurality of despread signals; and

the step of despreading the second plurality of spread-spectrum signals includes the step of filtering the second plurality of spread-spectrum signals, thereby generating the second plurality of despread signals.

17. The method as set forth in claim 13, further comprising the steps of:

despreading a third plurality of spread-spectrum signals within a third group, to generate, respectively, a third plurality of despread signals;

combining the third plurality of despread signals as a third combined-despread signal; and

the step of selecting includes the step of selecting one of the first combined-despread signal, the second combined-despread signal and the third combined-despread signal, as the output-despread signal.

18. The method as set forth in claim 17, wherein:

the step of despreading the first plurality of spread-spectrum signals includes the step of decorrelating, respectively, the first plurality of spread-spectrum signals, thereby generating the first plurality of despread signals;

the step of despreading the second plurality of spread-spectrum signals includes the step of decorrelating, respectively, the second plurality of spread-spectrum signals, thereby generating the second plurality of despread signals; and

the step of despreading the third plurality of spread-spectrum signals includes the step of decorrelating, respectively, the third plurality of spread-spectrum signals, thereby generating the third plurality of despread signals.

19. The method as set forth in claim 17, wherein:

the step of despreading each of the first plurality of spread-spectrum signals includes the step of despreading with a chipping-sequence signal having a time delay different from each time delay of each chipping-sequence signal used to despread other spread-spectrum signals of the first plurality of spread-spectrum signals;

the step of despreading each of the second plurality of spread-spectrum signals includes the step of despreading with a chipping-sequence signal having a time delay different from each time delay of each chipping-sequence signal used to despread other spread-spectrum signals of the second plurality of spread-spectrum signals, and having the time delay different from each time delay of each chipping-sequence signal used to despread spread-spectrum signals of the first plurality of spread-spectrum signals; and

the step of despreading each of the third plurality of spread-spectrum signals includes the step of despreading with a chipping-sequence signal having a time delay different from each time delay of each chipping-sequence signal used to despread other spread-spectrum signals of the third plurality of spread-spectrum signals, having a time delay different from each time delay of each chipping-sequence signal used to despread spread-spectrum signals of the second plurality of spread-spectrum signals, and having the time delay different from each time delay of each chipping-sequence signal used to despread spread-spectrum signals of the first plurality of spread-spectrum signals.

20. The method processor as set forth in claim 17, wherein:

the step of despreading the first plurality of spread-spectrum signals includes the step of matched filtering

the first plurality of spread-spectrum signals, thereby generating the first plurality of despread signals;

the step of despreading the second plurality of spread-spectrum signals includes the step of matched filtering the second plurality of spread-spectrum signals, thereby generating the second plurality of despread signals; and

the step of despreading the third plurality of spread-spectrum signals includes the step of matched filtering the third plurality of spread-spectrum signals, thereby generating the third plurality os despread signals.

21. The method as set forth in claim 17, further comprising the steps of:

despreading a fourth plurality of spread-spectrum signals within a fourth group, to generate, respectively, a fourth plurality of despread signals;

combining the fourth plurality of despread signals as a fourth combined-despread signal; and

the step of selecting includes the step of selecting one of the first combined-despread signal, the second combined-despread signal, the third combined-despread signal and the fourth combined-despread signal, as the output-despread signal.

22. The method as set forth in claim 21, wherein:

the step of despreading the first plurality of spread-spectrum signals includes the step of decorrelating, respectively, the first plurality of spread-spectrum signals, thereby generating the first plurality of despread signals;

the step of despreading the second plurality of spread-spectrum signals includes the step of decorrelating the second plurality of spread-spectrum signals, thereby generating the second plurality of despread signals;

the step of despreading the third plurality of spread-spectrum signals includes the step of decorrelating the third plurality of spread-spectrum signals, thereby generating the third plurality of despread signals; and

the step of despreading the fourth plurality of spread-spectrum signals includes the step of decorrelating the fourth plurality of spread-spectrum signals, thereby generating the fourth plurality of despread signals.

23. The method as set forth in claim 21, wherein:

the step of despreading each of the first plurality of spread-spectrum signals includes the step of despreading with a chipping-sequence signal having a time delay different from each time delay of each chipping-sequence signal used to despread other spread-spectrum signals of the first plurality of spread-spectrum signals;

the step of despreading each of the second plurality of spread-spectrum signals includes the step of despreading with a chipping-sequence signal having a time delay different from each time delay of each chipping-sequence signal used to despread other spread-spectrum signals of the second plurality of spread-

spectrum signals, and having the time delay different from each time delay of each chipping-sequence signal used to despread other spread-spectrum signals of the first plurality of spread-spectrum signals;

the step of despreading each of the third plurality of spread-spectrum signals includes the step of despreading with a chipping-sequence signal having a time delay different from each time delay of each chipping-sequence signal used to despread other spread-spectrum signals of the third plurality of spread-spectrum signals, having a time delay different from each time delay of each chipping-sequence used to despread other spread-spectrum signals of the second plurality of spread-spectrum signals, and having the time delay different from each time delay of each chipping-sequence signal used to despread spread-spectrum signals of the first plurality of spread-spectrum signals; and

the step of despreading each of the fourth plurality of spread-spectrum signals includes the step of despreading with a chipping-sequence signal having a time delay different from each time delay of each chipping-sequence signal used to despread other spread-spectrum signals of the fourth plurality of spread-spectrum signals, having a time delay different from each time delay of each chipping-sequence signal used to despread spread-spectrum signals of the third plurality of spread-spectrum signals, having a time delay different from each time delay of each chipping-sequence used to despread other spread-spectrum signals of the second plurality of spread-spectrum signals, and having the time delay different from each time delay of each chipping-sequence signal used to despread spread-spectrum signals of the first plurality of spread-spectrum signals.

24. The method as set forth in claim 21, wherein:

the step of despreading the first plurality of spread-spectrum signals includes the step of matched filtering the first plurality of spread-spectrum signals, thereby generating the first plurality of despread signals;

the step of despreading the second plurality of spread-spectrum signals includes the step of matched filtering the second plurality of spread-spectrum signals, thereby generating the second plurality of despread signals;

the step of despreading the third plurality of spread-spectrum signals includes the step of matched filtering the third plurality of spread-spectrum signals, thereby generating the third plurality of despread signals; and

the step of despreading the fourth plurality of spread-spectrum signals includes the step of matched filtering the fourth plurality of spread-spectrum signals, thereby generating the fourth plurality of despread signals.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,673,286 Page 1 of 3

DATED : September 30, 1997

INVENTOR(S) : Gary R. Lomp

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

At column 1, line 41, prior to "limited" insert --not--.

At column 1, line 64, prior to "meet" insert --to--.

At column 2, line 66, delete "co" and insert therefor --to--.

At column 4, line 20, delete "the power color, end signal" and insert therefor --power-command signal--.

At column 4, line 44, delete "An the" and insert therefor --At the--.

At column 6, line 21, delete "25".

At column 7, line 44, delete "my" and insert therefor --may--.

At column 7, line 63, delete "$(g-2T_0-t_{D1})$" and insert therefor --$(t-2T_0-T_{D1})$--.

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,673,286

DATED : September 30, 1997

INVENTOR(S) : Gary R. Lomp

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

At column 8, line 17, delete "15".

At column 11, line 47, delete "illustrated multiplier 117, eighth with seventh multiplier 117" and insert therefor --illustrated, by way of example, with seventh multiplier 117, eighth multiplier 118--.

At column 11, line 52, delete "$g(t-2T_0-T_2)$" and insert therefor --$g(t-2T_0-T_{D2})$--.

At column 15, line 44, delete "s(f)" and insert therefor --H(f)--.

At column 18, line 18, delete "power-compound" and insert therefor --power-command--.

At column 18, line 51, delete "25"

At column 19, line 50, delete "end".

At column 22, line 25, delete "ochers" and insert therefor --others--.

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,673,286 Page 3 of 3

DATED : September 30, 1997

INVENTOR(S) : Gary R. Lomp

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

At column 22, line 27, delete "race" and insert therefor --rate--.

At column 22 line 55, delete "BER~8x10^{-4}" and insert therefor --BER≈8x10^{-4}--.

In claim 3, column 24, line 40, delete "=he" and insert therefor --the--.

In claim 3, column 24, line 42, delete "ocher" and insert therefor --other--.

In claim 20, column 29, line 12, delete "os" and insert therefor --of--.

Signed and Sealed this

Twenty-first Day of July, 1998

Attest:

Bruce Lehman

BRUCE LEHMAN

Attesting Officer

Commissioner of Patents and Trademarks

Exhibit 6

InterDigital

Pay Up Or Else

Howard Goldberg wants every cell phone to use InterDigital's chip technology. He's got a bizarre way of wooing customers | BY ELIZABETH MACDONALD

INTERDIGITAL COMMUNICATIONS IS in the wireless business. But this King of Prussia, Pa. firm doesn't make any phones or handhelds. Instead it extracts money from companies that do. It has what it asserts is a library of 4,200 patents that govern the innards of wireless devices.

Howard Goldberg, the 57-year-old chief executive of InterDigital, says, "We're at the core of the communications revolution. We keep gaining strength because we've been in the forefront of invention. We've kept our foot on the pedal more than anyone." Goldberg says he's got 300 engineers working in hushed videoconferencing rooms he calls "ideatoriums," where they find new ways to increase the range and signal strength of cell phones.

But rather than earn cheers or envy for its research prowess, Goldberg's company has earned enmity for its hardball enforcement of intellectual property rights. Virtually all of its $33 million profit for the first nine months has come from dragging customers like Ericsson and NEC Corp. through legal disputes over patents. "Its strategy is so difficult," says Frank R. Marsala, an analyst at First Albany. "Everything it's done is about pulling teeth."

Goldberg, who is also a lawyer, says his tactic of fighting poachers is intrinsic to InterDigital's success. "It's what we have to do every day," he says. "This is not a situation where you can sit back and just let things happen."

InterDigital has only recently stopped being a big moneyloser. It turned a profit, before extraordinary items, in four of the last five years, but only five out of the last fifteen. It has generated free cash in only three years since 1988. Worrisome, as some of InterDigital's most valuable patents expire in 2006. But Wall Street loves this outfit. Shares trade at $20, or 28 times trailing earnings, giving the company a market value of $1 billion.

What's to like about this company? Lately investors have been enthusiastic about the potential for a big arbitration victory against Nokia and Samsung Electronics over its second-generation, or 2G, digital cellular technology. Goldberg has

JUSTIN STEELE FOR FORBES

done much to inspire this enthusiasm.

Last March InterDigital issued a press release announcing a patent victory over Ericsson and its joint venture called Sony Ericsson Mobile Communications, where the two agreed to pay InterDigital $34 million. In the release InterDigital declared that the settlement set a new, richer licensing rate for Nokia and Samsung, with royalties from them potentially hitting $180 million to $220 million over this year and next. Later, in their annual shareholder letter, Goldberg and Chairman Harold Campagna touted an even bigger 2G cash windfall from the four concerns of $360 million to $430 million by mid-2004. InterDigital's stock soon shot to $28, quadruple its lows of August 2002.

Not long after, insiders started dumping shares. Between March and early October, Goldberg and insiders like Mark Lemmo, an executive vice president, unloaded a net total of 111,000 shares for proceeds of $6 million. (Goldberg says he has raised his stake slightly, to 86,000, and has sold shares acquired in option exercises.) Goldberg is unapologetic, saying the company has strict policies on stock sales. "We're people, we all have needs," he says.

But with six months to go before that April 2004 target date, prospects for a gusher of cash look dimmer by the minute. Both Nokia and Samsung are adamantly refusing to pay the advertised sums. As Nokia had paid just $32 million in royalties to InterDigital between 1999 and 2001, and Samsung paid only $19 million from 1996 to 2001, it might be optimistic to expect hundreds of millions of dollars. Both are demanding sealed court documents from InterDigital's legal fight with Ericsson. While both declined comment on the arbitration, Nokia's spokesman William Plummer says: "Any party can file as many applications as they want to assert their intellectual property rights and declare they're essential, but that doesn't mean they are."

With InterDigital's 2G patents expiring, Goldberg hopes to cut deals for its newer patents on higher-speed third-generation, or 3G, technology that can help expand bandwidth for wireless e-mail or Web browsing. "Any company can design around our patents, but our inventions are the simplest, most elegant and cheapest way to make a handset," he says. Marsala at First Albany isn't so sure: "I think they have something defensible in 3G, but it's at least somewhat contentious what the strength is of its overall intellectual property." So far eight companies, including Sharp and Panasonic Mobile Communications, have signed on to the 3G licenses. Compare that to Qualcomm, with $985 million in licensing and royalty revenue and 120 3G licensees.

Moreover, InterDigital warned in its 10-K for 2002 that 3G manufacturers are reluctant to license its 3G patents "because a leading wireless company has agreed to indemnify them against allegations of infringement." Given that a mystery company—Qualcomm says it's not the one—will now protect companies from InterDigital's litigiousness, that eliminates much of the fear of shunning Goldberg.

InterDigital is making the most of its patent revenue. Ordinarily, because it's nonrecurring, money from legal settlements is recorded not as ongoing revenue but as "other income," says Charles Mulford, an accounting expert at the Georgia Institute of Technology. Despite telling investors in its annual report for 2002 that it would book legal settlements as "other income" (PricewaterhouseCoopers made the change after taking over from Arthur Andersen), InterDigital stuffed the $20 million it got from Sony Ericsson into revenue, with the other $11 million (net of an estimated $3 million insurance reimbursement) from Ericsson booked as other income. That $20 million was half of first-quarter revenue; the $31 million erased what would have been a quarterly loss. No cash actually came in until a $7.8 million payment in the second quarter, with another $7.8 million due by the end of the year.

InterDigital argues it was in the right because the $20 million deal technically was a new agreement to settle a separate patent dispute with Sony Ericsson. It's not the first time InterDigital made this move. Last year it transformed a $53 million legal settlement with NEC into a four-year revenue stream, recording $12.3 million in sales in 2002. The company says accounting rules allow for such treatment.

In any case, InterDigital may see its $33 million in profit for the first nine months nearly vanish because its insurer, Federal Insurance, is demanding a big $28 million cut of the Ericsson-Sony settlement to reimburse it for attorneys' fees it covered. This fight is now headed for arbitration.

Starting out in 1972 as International Mobile Machines, InterDigital made one of the earliest digital phones, the UltraPhone, but it never found a market. In the mid-1990s InterDigital began focusing on just making patented designs. As InterDigital was pulling away from making products, Goldberg was coming to power. InterDigital needed a lawsuit savant, and Goldberg fit the bill. A former special counsel at the Securities & Exchange Commission, he spent ten years in InterDigital's legal group.

Today Goldberg oversees a squadron of in-house lawyers, which can swell to dozens of outside lawyers if need be. They've taken their losses. In 1995 a jury threw out InterDigital's demand for $200 million against Motorola for patent infringement.

For now InterDigital has another fight on its hands. Four handset manufacturers—Nokia, Siemens, NTT Docomo and Ericsson—are sick of patent disputes and have jointly agreed to cap royalty rates on patents for a burgeoning technology known as wideband code-division multiple-access. The consortium has suggested the rate be set at around 5% of a handset's costs. "We want to keep it as low as possible, to prevent some companies from just making money with their patents, as does InterDigital or Qualcomm," says Siemens' spokesman Florian Kreutz. Goldberg says: "I don't believe this will substantially affect our business." That remains to be seen. ■

Most of its profit so far comes from patent disputes. "Its strategy is so difficult. Everything it's done is about pulling teeth."

Exhibit I

FD (Fair Disclosure) Wire

August 13, 2003 Wednesday

Transcript 081303au.736

LENGTH: 8407 words

HEADLINE: Q2 2003 InterDigital Communications Corporation Earnings Conference Call - Final

BODY:

OPERATOR: Good morning my name is Constance. I will be your conference facilitator. At this time I would like to welcome everyone to the InterDigital Communications Corp. second-quarter 2003 operating results conference call. All lines have been placed on mute to prevent any background noise. After the speaker's remarks there will be a question-and-answer period. (Caller Instructions). Thank you. Mr. Guy Hicks, Vice President of Corporate Communications and Investor Relations, you may begin your conference.

GUY HICKS, VP CORPORATE COMMUNICATIONS AND INVESTOR RELATIONS, INTERDIGITAL COMMUNICATIONS CORPORATION: Thank you. Good morning. Welcome to the InterDigital Communications Corp. operating results conference call for the second-quarter 2003. As Constance indicated, my name is Guy Hicks, and I'm the Vice President of Communications and Investor Relations. Joining me today on the call are Howard Goldberg, our President and Chief Executive Officer; and Rich Fagan, Chief Financial Officer. Before we begin, however, I need to remind you that in this call, we'll make forward-looking statements regarding our current beliefs, plans, and expectations as to our strategies, the Nokia and Samsung matters, expansion of our licensee base and pursuit of new business relationships a market opportunities, the benefits associated with the Tantivy transaction, our existing and future technology and product development programs, our revenues, expenses, and cash flow, our share repurchase program, and the performances of our licensees. Actual outcomes could differ materially from those expressed in any such forward-looking statements due to a variety of factors, including those set forth in the Company's most recent filings on form 10-K, 10-Q, and in this morning's release. Now, it's my pleasure to introduce our Chief Financial Officer, Rich Fagan. Rich?

RICH FAGAN, EVP AND CFO, INTERDIGITAL COMMUNICATIONS CORPORATION: Thank you Guy. Good morning to everyone. We were very pleased to provide solid results for second-quarter 2003. Our revenues grew nicely over comparable numbers for first-quarter 2003 and last year's second-quarter. Importantly, our cash position grew $33

million in the quarter as we ended second-quarter 2003 with our highest cash position ever. And, as we noted in our press release today, our cash position was further strengthened in early third-quarter 2003 by the receipt of approximately $24 million of initial payments, associated with a number of new or renewed patent license agreements. We were also pleased to announce that our Board has approved the repurchase of up to 2 million shares of the Company's outstanding common stock, reflecting its confidence in the Company's future.

Let's briefly review the numbers for second-quarter 2003. We reported revenues of $25.8 million in net income, up $3.1 million or 5 cents per diluted share. That compared with revenues of 25.1 million and net income of 2.4 million or 4 cents per diluted share in last year's second-quarter. Now, I will note at the outset, that direct comparisons of second-quarter 2002 are affected by the fact that last year's second-quarter included the recognition of 6.9 million of nonrecurring revenue from Kiasera (ph). Therefore, my comments will be directed at apples-to-apples comparisons without this item. We experienced very solid growth in second-quarter 2003 recurring royalties. These royalties jumped to 25.6 million from 16.6 million and last year's second-quarter and 17 million in first-quarter 2003. Royalties from NEC, Sharp, Ericsson, and Sony-Ericsson comprised 90 percent of total revenues in the quarter and drove the improvement versus both last year's second-quarter and first-quarter of this year. In second-quarter 2003 were all these related to recent agreements with Ericsson and Sony-Ericsson contributed to 4.8 million of the total. NEC contributed almost 40 percent of the total. That amount included 2.3 million from a true-up of NEC's projected versus actual royalties for first-quarter 2003 and solid royalties from second-quarter 3G product sales. Sharp Corporation, which continues to be an important element of our royalty revenue stream, has begun to take advantage of its position as a pioneer in camera handsets. And we look for them to start leveraging their position with Vodafone into supply arrangements with other leading non-Japanese carriers.

Now, moving on to the rest of the income statement — our second-quarter 2003 operating expenses increased a modest 1 percent over second-quarter 2002, while tax expense decreased due to the lower level of revenue subject to non-U.S. withholding taxes. Looking forward, we are optimistic that we'll continue to benefit from solid performances of our key licensees in the second half of 2003. We'll also continue to be aggressive in seeking to expand our licensee base and in pursuing other business relationships that could result in additional revenue over the next 12 months. We intend to complete the wideband TDD technology development program as planned. But we will delay investment in field trial demonstration products until 3G market demands warrant such investment. Nonetheless, we anticipate that our operating expenses and capital expenditures in second-half 2003 will increase slightly, as we examine and invest in growth and expansion opportunities and other strategic corporate initiatives. And, I think he goes without saying that our results could be materially affected by positive resolutions of issues with Nokia and Samsung. This concludes my prepared remarks. I will now turn the call over to Howard Goldberg. Howard?

HOWARD GOLDBERG, PRESIDENT, CEO AND DIRECTOR, I NTERDIGITAL COMMUNICATIONS CORPORATION: Thank you Rich. As Rich just presented, our very strong second-quarter performance reflects the success of our strategic licensing focus over many years and the continued impact of fiscal discipline. The fundamentals of our business are outstanding. These fundamentals include strong positive cash flow generation, through return royalties, and prudent cost and cash management. As we move forward, we're focusing our licensing, technology, and product development efforts on creating a broad-based revenue stream that spans multiple generations, multiple technologies, multiple standards, and multiple points in the wireless value chain. I'm very pleased to focus on the fact that over the past ten quarters, we have produced a compounded annual growth rate slightly above 50 percent in our recurring revenues. We're now approaching 500 million of cash receipts from patent licensing since 1995.

The number and quality of our patent licenses continues to strengthen. With approximately 70 percent of the world-wide TDMA and GSM handset market now under license to InterDigital, we're gaining greater transparency and predictability as our revenues increase. Our key licensees, both in 2G and 3G, include OEM providers extremely well positioned in their respective marketplaces. I'd like to take this opportunity to highlight just a few of our many licensees. Many of you have followed the outstanding product successes of Sharp and the leading position they're taking in camera phones. Likewise, NEC has enjoyed tremendous success in winning infrastructure business in the early 3G marketplace and is aggressively increasing its target position in the 3G handset market throughout Europe. Sony-Ericsson has been introducing a popular, broad line of 2G handset products, which are enjoying renewed market success.

No discussion of our licenses would be complete, of course, without comment on Nokia. The amount of money at issue with respect to the second period license is substantial. While we would prefer to finalize terms solely through negotiation, that path may not be possible in this case. Arbitration, a process contemplated by our license agreement with Nokia, has been initiated. I want to stress that this is a process that we will abide by, including all associated restrictions

concerning confidentiality. Let me stress a couple of other points. It's very important that everyone understand that our resolve remains completely intact. With our strong cash position, we are able to proceed with business as normal. We intend to take the negotiation and arbitration process through to completion in whatever form that may take. We have, as a Company, faced many challenges getting to this point. And we have always emerged as a better company. We intend to do so in this case.

Let me transition from discussion of Nokia and talk about -- briefly -- about the strong inventive culture at **InterDigital**. Since we were recognized by Inc. (ph) magazine for our inventive successes and the unique compensation structure that fuels those successes, we have risen to still higher levels. Our pace of internal invention in the first half of 2003 remain strong. In the first seven months of 2003, InterDigital engineers have been granted 34 patents. Compared to 41 patents granted in the entire year -- the entire year of 2002 and 27 patents granted in the entire year of 2001. This evidences strong performance and accomplishment for a Company of our size and as a result of substantial reinvestment for the future.

Also important to building enterprise value, are the objectives of broadening, strengthening, and diversifying our technology product programs and aligned engineering resources. We're approaching this evolution through internal refocusing, as well as through merger and acquisition activities. As exemplified by the Tantivy transaction. The Tantivy transaction brings a strong but lean team of 10, including very specialized engineers, who are engaged in developing technology platforms that meet our criteria for new business activities. In the case of the smart antenna technology, it has market applications on a generation, extendic, multiplatform, and cross-generational basis. The acquisition of Tantivy's wi-fi, or wireless LAN technology, enhances our positioning and the ability to influence the evolution of wireless LAN technology. While we're not presently planning on introducing products for the CDMA 2000 market, we did acquire full ownership rights to the Tantivy CDMA 2000 patents and effectively retired our prior potential earn out obligation of up to $24 million to Tantivy, and amount which is considerably in excess of the purchase price for substantially all of Tantivy's assets. We're going to use the people and the facilities of this acquisition to form the foundation of our new Melbourne design center. The geographic presence gives InterDigital a position and a growing and very dynamic telecommunications development area and opens the door and extended future business relationships and potential growth. We are also undertaking other internal activities which will broaden, strengthen, and diversify our technology and product programs. As existing programs are successfully completed, resources are being redeployed towards attractive opportunities identified in our innovation process. While these activities will in-part place extended focus on smart antenna and wireless LAN, we are also focusing on other market up opportunities that represent new areas of concentration for InterDigital. These areas are those where core competencies developed in the FDD and wideband TDD programs, are the value drivers -- such as interference management and multiple technology integration. In order to effectively control overhead, resourcing of these new activities will come through realignment of field trial product time-lines to better match indicated market timing in the wideband TDD program. We're continuing our core wideband TDD technology development. Geneva and Koln trade show demonstrations, operators support in econometric modeling, standards activities, and marketing communications activities.

The Company will also, in associated area, continue to explore the viability and profitability of the TD-SCDMA market and will participate in any appropriate opportunities. Simultaneously, we have initiated certain activities focused on government and military contracting. While we have generated a low level of revenues to-date in this area, we are expanding activities designated to determine how we can profitably participate in this market on a subcontract basis. We remain committed to aggressively pursuing new market and business relationships that would broaden our access to technology, diversify our future revenue streams, and create new avenues for accelerating growth. At the same time, we're focused on since sustaining our financial strength, a competitive differentiator in our industry and an essential element of our strategy to build long-term enterprise value in the company. For me and my colleagues, these are truly exciting times at InterDigital. And with that, Constance, let's open the call to questions.

OPERATOR: At this time, I would like to remind everyone (Caller Instructions). Your first question comes from Robert Steadman (ph), from Dimly

ROBERT STEADMAN, ANALYST, DIMLY: Good morning. During the months of May, June, and July, the four top members of management all sold a substantial share of their stock holdings in the Company. And this was to the mid to latter part of the negotiations with Nokia, the most critical period, probably, in the Company's history. Can you explain two things? Number one, how the window could've been open for insider selling at that stage of the most important part of these negotiations? And how, even as of July 6, when Howard Goldberg sold stock, the management had no idea that

these talks were not going well and were going to come to a very unhappy conclusion?

GUY HICKS: Bob, I'll handle that question. Our general counsel is advised of all relevant matters and considers them in determining whether or not have we are in an open period. For me to have a discussion with you about what was advised to our general counsel would require that we get into matters that are under confidence. And I certainly cannot do that. I would like to backtrack to your comment that the four most senior members of management sold substantial portions of their holdings during that period. And I will personalize it by referring to the numbers that are my numbers, which represent a minuscule portion of my holdings. The answer to the generic question, why does management sell at any point in time, is simply an issue of liquidity, diversification, and personal needs as they arise from time-to-time — justified against very narrow windows that management has available to them under Section 16.

ROBERT STEADMAN: To follow up on that, this process, theoretically, with Nokia, was triggered in mid-March. Is it your contention that from mid-March to July 6th, members of management, including you, had absolutely no conception that these talks with Nokia were not going well and arbitration might be a likely outcome?

GUY HICKS: I can't get into characterizing well or not well or anything such as that, Bob. I think that, as I said, most of this has to remain under confidence. It certainly is the case that when you have negotiations concerning substantial amounts of money, you expect there to be give-and-take and push-and-pull during the process of negotiation. And we had laid out from the very beginning the possibility that this matter could resolve in arbitration. We had, even in the first — as early as the first calls, talked about the difference scenarios that could play out, including the fact that if the matter when into arbitration, the likely result would be in next year, not this year. And it has always been a part of the process that we were very open about. And one which we don't feel fundamentally impacts our ability to conduct business in any way.

ROBERT STEADMAN: Okay. Let me congratulate you on your timing then. Thank you.

OPERATOR: Your next question comes from Michael Cody (ph), Sidoti & Company.

MIKE CODY, ANALYST, SIDOTI & COMPANY: Thanks. Good morning gentleman. Just a few questions. Was there any — you mentioned the true-up from NEC, related to the first quarter. Was there any true-up from Sharp related to the renewal of the 2G agreement?

RICH FAGAN: The only thing, Mike, this is Rich Fagan. As we had indicated in the last call, the prior agreement expired on March 20th. So, we had a little stop period of about to 10 or 11 days that it included in the second quarter. But, it's not material to the overall.

MIKE CODY: Okay. And then, NEC, is their prepayment exhausted at this point. And they're just paying on an as-you-go basis?

RICH FAGAN: Yes. We had indicated last time that they had exhausted their prepayments and they're paying current now.

MIKE CODY: Could you characterize the difference in — I mean, obviously, you get the discount to prepayment — so how much greater the royalties are, because their selling on an as-you-go basis, as opposed to having been exhausted versus the prepayment?

GUY HICKS: We typically don't say what the terms of discounts for — that we provide licensees. But, I think you can see — you can kind of back into some of those types of discounts, just by looking at what we have disclosed on other relationships, you know, in terms of discounts. Typically there's a benefit to both parties. One, there is a discount that they get. But typically, they have to expend a lot of cash that is non-recourse to us. It's a win-win for both parties. And as you have seen in the past, sometimes companies make decisions that impact that going forward. And cash remains with us.

MIKE CODY: Right. Okay. Related to expenses in the second half of the year. You mentioned increasing modestly as invest in some of these strategic initiatives. Could you be a little more specific on what you think modest is. Was the increase in the June quarter versus the March quarter modest? Or was it less than modest?

HOWARD GOLDBERG: I think, if you look sequentially, that's in the range of modest, Mike. There's no guarantee on the exact numbers. And that's why we don't get very specific, in terms of percentages. I think that modest increases you'll see sequentially. And then you'll see some amount, due to adding a facility in Florida. We added about 10 people in Florida. So, you have 10 people, plus an office in Florida. And once we resolve the purchase accounting for those assets, we'll also have the non-cash charge associated with purchase accounting activity associated with that. So, you'll

get something from the base that was in-place. And then some impacts from the recent acquisition of assets.

MIKE CODY: Okay. And that will show up in your patent administration licensing?

RICH FAGAN: No, the development -- the Melbourne aspects -- the development group will show up in development line. The amortization or depreciation would show up in patent licensing and administration though, from the purchase accounting.

MIKE CODY: That's what I was referring to. No problem. One quick thing on expenses. Could you explain to me kind of how sales and marketing expense works? Why it was down sequentially so much? Kind of what that line item will do?

RICH FAGAN: Sure. The sales and marketing expenses is comprised of our business development group, as well as corporate marketing group. And what impacts that line are things like tradeshows and actually business development activities, etc. So, the timing of some of our activities this year were impacted by SARS. We actually managed some of our tradeshow costs down a little bit from prior years. And we also had some impact from restricted stock amortization for some of the people in those groups for a grant that was made back in 1999 that finished up in late October -- November of last year.

MIKE CODY: Okay. Thank you very much. Nice quarter.

OPERATOR: Terrence Weiland (ph), Piper Jaffray.

TERRENCE WEILAND, ANALYST, US BANCORP PIPER JAFFRAY: Hi. Good morning. Great. First of all, nice job on the results. It sounds like you have redirected your WTDD strategy this quarter. And it seems like you're de-emphasizing it as your sole pact to 3G. Can you discuss the broader dynamics and the considerations that were processed in that decision? And also talk about the timing of that decision? Is it something you have been considering for the past couple of quarters? And then I'll ask a follow-up. Thanks.

HOWARD GOLDBERG: Terrence, let me is sort of put a slightly different gloss on that. With respect to our wide-band TDD efforts, we consider ourselves ahead of the critical market window at this point in time. We're constantly recalibrating to the market. And, as you are well aware, the FDD portion of the market is rolling out somewhat slower than expectations have been for a period of time. We have been watching that, to make sure that, from a product point of view, we don't get too far ahead of the market. Because there are no real economics in doing that. In parallel, we've been going through a process of developing innovation ideas and identifying opportunities. And we are doing that primarily internally at this point. When we faced what was a very happy challenge of trying to resource new opportunities that we had identified, that we're very excited with -- with the prospect of staffing those particular opportunities. It was either a matter of increased overhead to be able to address those opportunities or recalibrate back on WTDD, where we were ahead of the critical market window -- in any case, and use those resources for the innovation program. It made imminent sense for us to do the latter. As I indicated during the conference call, all the other key elements of the program including demonstrations in Geneva and Koln, work with the operators including the Koln metric modeling, core technology development, etc., are considered -- are moving forward under original plan. So, we are very -- I think it was a path among various options that made imminent sense for us. In terms of the innovation opportunities are exciting us; I certainly see the acquisition of Tantivy as complementary to efforts that were already underway, in terms of wireless LAN and smart antenna. It was in-fact, those preliminary focuses that brought Tantivy to our attention. We are also taking very strong core competencies that were developing in the WTDD program, including management of interference and multiple technology integrations. And we see many ways that we can bring those into the market. But, as I am sure you could understand, for competitive reasons, I don't want to get any more granular in identifying what those opportunities are specifically. We believe that we may be ahead of the market in identifying those opportunities. And we want to retain those competitive advantages until the time it's appropriate to provide more granularities.

TERRENCE WEILAND: Okay. Great. Thank you, Howard. If I could just dig a little bit deeper on that. It sounds like your investment plan for WTDD will continue through the development. But then, the field trials will change a little bit. Is it fair to say that you have allocated what you initially planned for field trial demonstration to these new programs of smart antenna, wireless LAN, and interference management? In other words, are you really ramping up your development to a couple of these areas, where prior, you hadn't really made as much of a focus? And then, as a follow-up to that, do you anticipate in the future, as you do consider more network integration and interference as a business model, do you consider going more to a service business model, as you scale over the next few years?

HOWARD GOLDBERG: First, to address the first element of your question. This is a serious ramp-up of those

programs. These are serious opportunities that we have identified. They fit extremely well within our core competency. And as I indicated in my script remarks, one of the elements that we are looking at is participating in other points of the value chain. It means that we are moving away from being solely reliant on dealing with the customers in the place in the value chain where they're presently positioned. We certainly would look at the possibility of working directly with operators, if particular skills in interference management where others created a business model that we could profit from. And we are developing much, much greater understandings and opening continuing dialogue and key relationships with operators, as we work with them on wideband TDD in the econometric modeling. That's a different way participating with the industry than had been our experience over many years. And it gives rise to many new opportunities. So, we are bottom-line-oriented. We are market-oriented and all of the things that you articulated, Terrence, there are certainly opportunities that are within our focus for the future.

TERRENCE WEILAND: Okay. Thanks Howard. Nice job and good luck in Q3.

OPERATOR: Mike Lockley (ph), RBC Capital Markets.

AMIT KAPUR, ANALYST, RBC CAPITAL MARKETS: It's actually Amit Kapur for Mike Lockley. Just a couple of questions. First is just more of a housekeeping -- and I apologize if you can't answer this. But have you actually filed your response to Nokia's arbitration request? And has arbitration with Nokia actually commenced now?

HOWARD GOLDBERG: We have not filed our formal response at this point.

AMIT KAPUR: Okay. In terms of the license -- the growth in license agreements over the next 12 months, can you give us some color as to what proportion of the maybe 2.5G -- I'm sorry -- 2G and 2.5G agreements versus negotiations for 3G agreements?

HOWARD GOLDBERG: I would say this. We have historically resisted projecting specific numbers, because the nature of the licensing process is that it extends over a fairly extensive period of time. And it's really hard to be able to gauge exactly when it happens. You start to negotiate against yourself if you put numbers out there that everyone is watching. We're focusing on the fit and the strategic value of next licensees down the line. We have feet on the street as we're talking that are pursuing licensing opportunities. Discussions have been proceeding as normal. They have not changed since we indicated that we saw good positive discussions after the signing of the Ericson and Sony-Ericson agreements. And we see value in both. The 30 percent of the market that is not licensed to us -- the handset market and the TDMA and GSM -- represents opportunity, as does 3G, where we are looking at the -- where we have major players in the marketplace that are making substantial contributions to our revenue stream. But we intend to focus on both sides of 3G -- the CDMA 2000 side and the WCDMA side. And we have a nice challenge in front of us. Fifty percent compounded annual growth rate is not something that most companies could talk about over the past ten quarters. And the challenge in front of us is to keep sustaining those numbers and improving. And we will take on that challenge.

AMIT KAPUR: Okay, great. Final question. Could you comment on what your 3G licenses are seeing, in terms of traction for 3G? And can you give us a sense of if you're seeing more traction in Europe or Asia?

GUY HICKS: There's a lot of messages out there. And they tend to be somewhat mixed, at this point in time. The early implementation of CDMA -- I'm sorry -- of wideband CDMA, or IMT 2000, in Japan at the beginning, is lower-than-expected take-up. And that is largely attributable to the lack of Legacy network in Japan. They now seem to be picking up speed and MTD Docomo, appears to be gathering momentum. J-Fon with its Vodafone alignment, appears very positive, in terms of implementation in Japan. Throughout Europe, operators are starting to get their hands on it. Inter-operability problems, particularly on the handset side, are being addressed. Exactly when they will be overcome -- this next month or four months down the line -- it's very hard to say. But operators, increasingly, over the last quarter or two, seem to have -- at least in some significant cases -- turn the corner. They're producing good operating results. They're healthy. They're focused on the implementation of infrastructure that is shipped and in-place, but in many cases not turned on. And we're starting to see first waves of 3G -- very 3G focused type of applications coming, such as I-shot, which is sort of the picture-oriented follow-on to Li-mode (ph) in Japan. When you start to see those leading indicators, that's saying to you business is starting to gather momentum. So timing -- a little bit of an issue to have the transparency to address timing directly. But, we are encouraged overall by what we see.

RICH FAGAN: This is Rich Fagan. I think the other item to add, as you compare to say -- to a year or a year and a half ago, is what -- the thing that is encouraging is you're seeing a lot more handsets out there -- 3G now. And, as you know, people are reluctant to put infrastructure in, without handsets to generate some revenue off of that infrastructure.

And you are seeing a lot more vendors out there with 3G handsets coming out. That's encouraging.

HOWARD GOLDBERG: And starting to take on the right form factors and pricing.

OPERATOR: Gail Warmington (ph), GailWar Capital Management.

GAIL WARMINGTON, ANALYST, GAILWAR CAPITAL MANAGEMENT: I'm just trying to get clarity, in terms of your deferred revenue. What portion do you anticipate recognizing this quarter?

GUY HICKS: What portion this quarter?

GAIL WARMINGTON: I mean, the September quarter, for your deferred revenue?

RICH FAGAN: There are pieces in there, that if you look at our balance sheet, you can see that we typically will show a current portion of the balance sheet. And usually a fourth of that we get recognized. We recognize -- for example, for Ericsson, it's 1.5 million a quarter. For the NEC 2G agreement, there's usually about 3.2 or $3.3 million. And then, there's an additional $1 million of FAS 101-related adjustments. Beyond that, we recognize deferred revenue, based on the exhaustion against prepayments from licensees who have made prepayments, such as Sharp and others.

GAIL WARMINGTON: Okay. Thanks a lot.

OPERATOR: John Bucher (ph) of Harris, Nesbitt, and Gerrard.

JOHN BUCHER, ANALYST, HARRIS, NESBITT, AND GERRARD: This is John Bucher. Good morning. The wideband TDD, can you say what percentage of work remains on the wideband TDD development effort?

HOWARD GOLDBERG: I don't know if Rich has in hand a precise number. But, we are in the advanced stages of verification, integration, and testing. Near-term deliveries to Nokia and working towards final resolution of a number of technological issues that just have to be buttoned up over the next several quarters. So, it is very advanced (multiple speakers) of our non-product expenditures in that effort.

RICH FAGAN: We're at the stage of really completing and validating the technology. Prior to that, what we had talked about is field trial demonstrations. So, as Howard mentioned, we'll do Geneva and Koln demonstrations. And there's some technology development associated with that and some other aspects to complete the technology over the next several quarters.

JOHN BUCHER: So separate of any statement of work that you've got with Nokia to complete, just in terms of your ability to market that technology, if and when you see industry demand and readiness for that -- you have completed the vast majority of the development work?

GUY HICKS: We are very well along.

JOHN BUCHER: Then, on a totally separate topic. Do your licensees report units? And is that behind the royalty computation? And if so, do you have an estimate for -- I know NEC was a big contributor in the wideband CDMA side. Did you have any estimates for the 3G units shipped that are behind your royalty numbers for the June quarter?

GUY HICKS: For the June quarter, they have provided a report as to the detail behind that. Obviously, we can't provide the details of that, because that's confidential between us and them. But all market -- all market reports show what NEC and others have done, including Sharp. Sharp is very transparent on their own web site.

JOHN BUCHER: Last question. On the additional work that -- you are refocusing of the development work. You mentioned government and military contracting -- possibly being a subcontractor there. Is your focus on that particular initiative, as well as some of the others that you mentioned there, more engineering services focused, to be sort of a contract engineering services provider? Or is it more product focused?

GUY HICKS: John, it's really a mixture. There's -- increasingly the government is looking to wireless communications as part of a strategy for dealing with a number of contingencies. One of the dynamics that we've seen in play is that the government is actually on the leading edge of advanced product of implementation. And it's sort of flip-flopped from four or five years ago, where the commercial market tended to be somewhat ahead of the generalized government military market. So, it represents an opportunity for us, using our background of technology, to work with the government, both in advancing the technology. But also moving toward productization, in a way that could be both funded and then utilized in the commercial domain, when the commercial arena catches up with the government implementation.

OPERATOR: Frank Marsala, Helpern Capital.

FRANK MARSALA, ANALYST, HELPERN CAPITAL: Hi guys. How are you doing? I just want to follow up. I'm trying kind of get a sense of revenue run-rate for the quarter. So NEC, the true-up for NEC was about 2.3 million. Let me ask this question first. Are there any expenses associated with a true-up such as this? Is there any expense recognition, as well?

RICH FAGAN: Yes. In terms of revenues, when they come in — basically, there are some commissions that get recorded in the patent licensing administration line. And then the withholding taxes. On Japanese licensees, the withholding tax is 10 percent. So, until we start recognizing taxes on a normal basis, we are expensing at the withholding taxes and any AMT costs associated with profitability. But that is not linked to any particular revenue line.

FRANK MARSALA: So there is commissions associated with the NEC true-up as well?

RICH FAGAN: There is some level of commissions with most of our revenues.

FRANK MARSALA: You said Sharp was not material for the quarter? Could that be something like $500,000? Or is that an approximate — is that a reasonable number to be using?

RICH FAGAN: I'm sorry — are you talking about the stub period?

FRANK MARSALA: Yes. The adjustment for Sharp.

RICH FAGAN: It was less than $1 million.

FRANK MARSALA: Less than $1 million. Okay. Then — so that would say somewhere around 23 million or so, is probably about a right run-rate, by my numbers. So that was good. Then, on expenses. Should we continue to see about the levels we have seen in the second quarter, going into the third quarter? Or — I noticed in the past periods, the third quarter could be lower than the second quarter. How does that relationship shape up?

GUY HICKS: I think I tried to address this with Mike Cody a little bit earlier. But let me take another shot at it. There are a number of things that influence that. The decisions that we make on any particular program, whether or not we need outside assistance for any aspect of things — whether we have to buy tools etc. — can impact the development line. There are other factors that impact us, in terms of — even G&A, that impacted us. One of the things that has impacted us in the first half of this year — and we don't see it abating — to a large degree, is the whole issue of being a public entity. Our corporate governance costs are increasing. The post-Enron era — I'm sure you have seen the reports in the press of how much it costs any particular company. We've not actually said here's the X amount of dollars it's costing us. But I can tell you it's impacting our G&A line, because we — we have very good cost controls and prudent cost management throughout the Company. But we are impacted by this. So our D&O insurance is up year-to-year. And it has nothing to with anything we have done. It's a focus on the environment. We meet with insurance carriers and they indicate to us that our governance is very strong. But by-and-large, you are going to get those increases in that line as well. So, to circle back to your question, I just wanted to put in perspective. You've got a number of things that can influence your sales and marketing activities and the level of travel, which we expect, in terms of business development to pick up in the second half of the year. We didn't travel as much, because of SARS, in the first half of the year. Our patent and licensing activity will increase. And then the fact that you're getting increases from — some degree of increase from the recent asset acquisition from Tantivy. So, you should get some increase over second-quarter.

FRANK MARSALA: Then, just a Nokia question on that issue. Is there any leverage that you guys have today? Is there anything you can do to influence Nokia to bring this matter to a close — here I'm talking about things like bringing injunctions against them — shipping handsets — things of that sort of. So, I'm curious about that.

HOWARD GOLDBERG: Let me first say that we certainly will look at every point of leverage. The dynamics in a situation such as this are very important. We will look — and have been looking — at how we can drive this to a successful resolution. Through internal and external resources. One of the ways that leverage is best used is as a surprise or — certainly you don't want to create an anticipation of anything that you may do. So, the answer is yes. But I would be very reluctant to talk about it and layout our plan for dealing with this particular matter.

FRANK MARSALA: One of the issues that I continue to look at, but I don't really have clarity on the impact to your businesses is this issue of the indemnification that's going on out there. And it's been in your SEC filings and things of that sort. What is it that you guys think about doing, when you see something like that? What action can you take? How

impactful is that? I just want to get a better sense of where that --

HOWARD GOLDBERG: Let me, if I could, just put a perspective on that. I think that was laid out in the 10-K as one of a number of things. What we were attempting to do in the 10-K was put a little bit of color on what does the process look like? What does the Company experience as it goes out and attempts to license? Why is it such a difficult effort? Why do you have to have a very high-degree of skill and competency in this area? Why is it such a specialized area? So we sort of laid out -- we walk in the door. And these are the type of things that we are presented with, to attempt to delay the process, to attempt to make the process of a defensive one for us, and to change the dynamics of negotiation. These are things that the whole suite of the elements that are put in front of us in attempts of delay and defensiveness are the very things that we've been encountering for many years. And we have entered into a number of license agreements and important renewals, since the period of time that that was laid down in our 10-K. I'm not telling you to ignore it. But I am telling you that it was laid out as a part of the overall environment that we operate in. And that is all it was intended to do.

FRANK MARSALA: And then the last question I have, Howard, is when will you be able to layout a time-line for the arbitration with Nokia that gives us a sense of how this thing can move along, rather than just a kind of the 9 to 12-month window? Is there a time-line created by the arbitration body, for example?

HOWARD GOLDBERG: Once there is a panel -- a body, then it would be up to them to set the respective time-lines. And we would then have to then determine what's under confidentiality and what's not under confidentiality, if this process goes that far. Bill, in the most recent conference call, dealt with it as best we could at this point, which is to layout general -- sort of generic parameters, as to timing of arbitration. And, at this point in time, we have no specific knowledge that this particular process should go that far. It's going to deviate from the generic norms in any great manner.

FRANK MARSALA: Would to be up to just give us a sense then, after your response to the Nokia filing, about how long it will be before the arbitrators are chosen -- about how long that process would take?

HOWARD GOLDBERG: It would not be immediately after that filing. It would be somewhere further down the line, when there has been a complete empanelling and requisite level of procedures and processes before it's been laid out.

OPERATOR: Kevin Dede (ph), Merriman & Co.

KEVIN DEDE, ANALYST, MERRIMAN & CO.: Good morning guys. Congrats on the numbers. Apologies in advance for the remedial nature of my question. Could you review again, what you think your technology focus will be in Melbourne?

HOWARD GOLDBERG: Well, we have a group of highly specialized engineers who have concentrated on wireless LAN technologies and smart antenna. They have a legacy of having worked on a CDMA 2000-related product. That's the basic competencies of that design center. One thing that's important to us is the positioning in Melbourne, because it is an area of very substantial wireless telecommunications focus. We have -- we're going through a process of integration right now to examine exactly how we are going to use them. It would be fair to say that they will be integrated into other activities, not strictly and just focused on those particular areas -- but others in Melville or King of Prussia (ph) or Montreal or Munich -- might also bring their competencies as an additive to -- in the areas that Melbourne is working on. So, let's say that substantial focus initially on wireless LAN -- smart antenna. And that will evolve over time to an integrated research and development center that can participate in other areas of innovation focus along with us.

KEVIN DEDE: Okay. So, am I correct in assuming that the development you're working on with Philips is wide-band TDD stuff?

RICH FAGAN: Were not working on anything with Philips. Do you mean Nokia?

GUY HICKS: No. I thought you were in an agreement with a semiconductor maker?

RICH FAGAN: No. We've been working on FDD software protocol stacks with Infineon. I think that may be what you're referring to.

KEVIN DEDE: Okay. Right. That's it. Lastly, is there any technology overlap with TD-SCDMA in China?

HOWARD GOLDBERG: There's substantial overlap. We have investigated the percentage -- the relationship between the core technology that is part of wideband TDD and the core technology that is part of TD-SCDMA. And at their heart, they're both TDD technologies. The high chip rate versus the chip rate deviations makes for certain changes. But as we talk with prospective customers and partners in China, are value, in terms of the background technology that we have, the

core competencies that we develop, the understanding — deep understanding — world-class understanding — that we have of TDD technology is of substantial interest to them.

KEVIN DEDE: Then, how would you go about enforcing your intellectual property rights there?

HOWARD GOLDBERG: I won't pretend that China is the same as everywhere else. Bringing value-added propositions to a strict patent-licensing scenario certainly helps with the proposition. But China has also been very public, in terms of its commitment to abide by — as part of the WTO admission — to abide by major commercial conventions throughout the world, including the area of IPR, where there is a substantial focus. And one of the best ways that they can demonstrate WTO compliance is to enter into intellectual property agreements with companies that have a clear position in their respective markets. We believe we have a very clear position, as a result of over thousand contributions to the TDD standards bodies in over 600 excepted, contributions, in terms of the role we have played in the architecture and defining of TDD technologies.

KEVIN DEDE: Howard. I'm clearly not going to disagree with your position. I am just curious on how — what processes you would put in place to make your position known and collect on the investment that you have made?

HOWARD GOLDBERG: I think our position is already well-known, in terms of collection. That is something that we will deal with when there is a market for TD-SCDMA products. And I would not publicly discuss, at this point in time, that particular issue before the market emerges.

RICH FAGAN: Kevin. This is Rich. What I will say is that, as you probably know, we have a pretty strong patent licensing group, who is active around the world. And we're always considering our opportunities and the timing of those opportunities and the appropriate level of resources to employ against them. So, China is not an area that we're forgetting. But we're also being choiceful in our allocation of resource and the timing of the allocation.

HOWARD GOLDBERG: It's counterproductive at this point to waive the dagger, especially when the market has not yet emerged. But we are very, very confident about our positioning.

KEVIN DEDE: Very good. Lastly then, would you mind giving me an update on where Infineon is and your work with them and how that is progressing?

HOWARD GOLDBERG: Kevin, Infineon is moving along very well. It's a very good relationship that has grown in quality over the period of time that we're working with them. They are very seriously addressing the prospective 3G market. They have an important relationship — the start core that is going to help them address that market. And we are very important embeddive to contact for Infineon. We feel good about how they're positioned. And they are focused and moving ahead.

KEVIN DEDE: Thanks very much for taking my questions gentlemen. And congrats again on the results.

OPERATOR: Mason Sexton, Harmonic Research.

MASON SEXTON, ANALYST, HARMONIC RESEARCH: This is Mason. Just quickly, could you comment on why you sealed the Ericsson negotiations — why it was sealed by the court?

HOWARD GOLDBERG: That was a decision that was made by the judge in the case. And it — there was a lot of proprietary content that was part of the litigation.

MASON SEXTON: So it related to the intellectual property issue?

RICH FAGAN: Sure, it was a decision that both parties made, along with the judge.

MASON SEXTON: Do you have any comment on what the likelihood is that Nokia will be able to reverse that?

HOWARD GOLDBERG: No, we're not going to speculate on it. I think the important thing to recognize is that the matter was sealed by a Federal judge. They don't do things without careful consideration of public policy issues and particular philosophies — overriding philosophies in the context of particular circumstances.

MASON SEXTON: Lastly, you may have covered. But, just want to get some clarification. What has counsel advised you, as to the likely timing or the length of time it will take for this process with Nokia to work itself out, in terms of the — ?

RICH FAGAN: That's one we've kind of covered a couple of times here. Basically, if have the opportunity to listen to

our conference call that Bill Merrick participated in, we kind of laid out the normal process for arbitration. And that -- this is a normal process which we'll go through. It takes its own ebbs and flows. But our recent experience in arbitration over the last couple of arbitrations is that this could take around a year -- all told. And throughout that process, there's opportunities for discussions and negotiations, beyond what the lawyers are doing.

OPERATOR: (Caller Instructions) Ladies and gentlemen we have reached the end of the allotted time for questions and answers. Mr. Hicks, are there any closing remarks?

GUY HICKS: Other than to say thank you, Constance, for moderating our call. And we appreciate all of you participating. This concludes our second-quarter 2003 call. Thank you.

OPERATOR: This concludes today's InterDigital Communications Corporation's second quarter 2003 operating results conference call. You may now disconnect.

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